Report No. FHWA-TS-78-205

GUIDELINES FOR USE OF FABRICS IN CONSTRUCTION AND MAINTENANCE OF LOW-VOLUME ROADS

by

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Reprinted by:
U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Offices of Research and Development
Implementation Division
Washington, D.C. 20590

Prepared by:
FOREST SERVICE
(Pacific Northwest Region)
U.S. DEPARTMENT OF AGRICULTURE
Washington, D.C. 20013

N O T I C E

Reprinted 1978

GUIDELINES FOR USE OF FABRICS

in

CONSTRUCTION AND MAINTENANCE

of

LOW-VOLUME ROADS

by

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June 1977

FOREWORD

This publication is written to increase awareness and improve understanding of the function and uses of fabrics in construction and maintenance of low-volume roads. The rapidly moving technology and increasing availability of fabrics for use in construction combined with the large volume of road construction and reconstruction (approximately 2,500 combined miles annually) by the Forest Service in Region 6 makes this publication necessary.

The report is written not as an end product, but as the beginning of a documentation and reference process for use of fabrics in construction.

The report contains nine chapters numbered independently to facilitate its use as a beginning point and encourage its revision and updating. Appropriate chapters will be revised as new information, standards, and guidelines are learned or developed.

Each chapter is the text material for the "Fabrics in Construction" reference notebooks prepared for the National Forests in Region 6. Similar reference notebooks can be prepared by combining this report with selected reports and manufacturers' literature contained in the Region 6 reference books (see Chapter 8).

Much of the information contained in this report is subjective. The writers prepared the report based on discussions, technical reading, and personal experience to improve the state of knowledge and understanding.

Thanks go to Bill Vischer, Willamette N. F., Darryl Greenway, Siskiyou N. F., and Robert Mitchell of the Regional Office, for technical review of this report. Special thanks go to Beverly Dove for her patient and expert typing of the whole thing.

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SYMBOLS

a	Soil strength factor for pavement materials.
b	Footing width.
C	Soil cohesion.
CBR	California Bearing Ratio; an emperical measure of soil strength.
d	Depth below the top of a retaining wall.
d_f	Depth from the top of a fabric retaining wall to a lower fabric layer.
D_{50}	The sieve size at which 50% of the soil is finer.
E.O.S.	Equivalent Opening Size; the size of the mesh openings in a fabric corresponding to the nearest standard sieve size.
gm	Grams.
G.R.	Gradient Ratio
i_f & i_s	See Gradient Ratio in Definition Section.
K_o	At rest pressure coefficient;
L_e	Length of embedment of fabric layer behind the failure plane.
L_o	Length of overlap of fabric layer at the face of the retaining wall.
m	Meter.
N_c, N_q, N_γ	Bearing capacity factors used in the Terzaghi and Meyerhoff equations.
oz	Ounces.
P_A	Pullout resistance; frictional resistance developed between fabric and soil in a fabric retaining wall.

psf	Pounds per square foot.
psi	Pounds per square inch.
q	Bearing capacity of a soil as given by the Terzaghi and Meyerhoff equations.
q	Vertical overburden pressure at the footing level.
R	Straight line distance from point of load application to point at which lateral pressure is being calculated by the Boussinesq equation.
S	Tensile strength of fabric used in fabric wall design; given by O.S.U. ring strength.
X	Perpendicular distance from a retaining wall to the point of application of the load.
Y	Horizontal distance parallel to the wall from point of load to point on retaining wall where pressure is being calculated.
Yd^2	Square yards.
Z	Vertical distance from point of load to level where lateral pressure is being calculated on a retaining wall.
γ	Unit weight of soil.
σ_{ho}	Lateral earth pressure.
$\sigma_{h\ell}$	Lateral live load pressure.
σ_h	Total lateral pressure on the sum of earth and live load pressures.

DEFINITIONS

Abrasion Resistance (Pounds): ASTM D-1682 Grab Test using one square inch jaws and a travel rate of 12 inches per minute, after abraded as in ASTM D-1175 Rotary Platform, Double Head Method, rubber-base abrasive wheels equal to CS-17 "Calibrase" by Taber Instrument Co.; one kilogram load per wheel; 1,000 revolutions.

Burst (ASTM D751, Diaphragm Bursting Testor, Pounds): The test is used to determine the equivalent hydrostatic force required to fail the fabric in a specified test ring.

Calendering: The process of pressing cloth between rollers to give it a smooth surface. The process is usually associated with heat to give a permanent set to the fabric.

Cut Strip Test (ASTM D-1682-64, Pounds): A strip test in which the specimen width is secured by cutting the fabric, (typically one-inch square jaws and a travel rate of 12 inches per minute).

Elongation (%): The ratio of length of a fabric test specimen (between jaws) at failure to its length before failure, expressed as a percent.

Equivalent Opening Size (EOS): EOS is the number of the U. S. Standard sieve having openings closest in size to the filter fabric openings.

Fill: Perpendicular to the axis of the fabric

General Shear: A shear failure where a footing displaces soil which shears along a circular failure arc causing a bulge of soil adjacent to the footing.

Grab Test (ASTM D-1682-64, Pounds): A test in which only a part of the width of the specimen is gripped in the clamps (typically one-inch square jaws and a travel rate of 12 inches per minute).

Graded Rock Filter: A filter consisting of rock graded from coarse to fine such that they allow drainage of water while providing protection from intrusion of soil particles.

Graded Sand Filter: A filter consisting of layers of sand of different gradations such that they allow drainage water while providing protection from intrusion of soil particles.

Gradient Ratio (G.R.): The gradient ratio is the ratio of the hydraulic gradient over the fabric and the one inch of soil immediately next to the fabric (i_f), to the hydraulic gradient over the two inches of soil be tween one and three inches above the fabric (i_s). Measured in a constant head permeameter with a four-inch thick soil sample over the fabric and open drain rock under a total head of about 12 inches.

Length: The lengths shown are the standard uncut, unsewn lengths of the fabrics that are commonly available.

Local Shear: Bearing capacity failure characterized by vertical settlement of the footing due to shearing of soil at the edge of the footing.

Needle-Punching: The process where barbed needles are punched through the cloth to entangle the fibers.

Non-Woven Fabric: Fabric made from fibers spun in a continuous process to produce a random pattern, usually no distinct measureable openings.

Open Drain Rock: Drain rock having a permeability $>$ 6,000 ft./day (generally has less than 5% passing the No. 4 sieve).

Oregon State University (OSU) Ring Test (Pounds/Inch): Test developed at Oregon State University, Corvallis, Oregon during testing of fabrics for use on low volume roads. The test determines a fabric strength in pounds per inch of fabric and percent elongation at failure. The fabric is gripped in a 6-inch inside diameter outer ring grip and in a 5-inch diameter center plunger (approximately 1/2 inch between the edges of the inner and outer grips). The load and elongation recorded during failure are based on the beginning length of the fabric between grips (radial length) and the final length at failure. The final length at failure depends on the vertical movement of the plunger and is measured along the plane of the fabric at failure. The strength per inch is determined by dividing the radial load in the fabric by the circumference of the plunger. Test was performed at a plunger travel rate of 12 inches per minute for the values listed in this report.

Percent Opening Area: The percent open area is the visible net area of a fabric that is available for water to pass through the fabric. This value is normally determinable only for the woven or non-woven fabrics having distinct visible and measurable openings that continue directly through the fabric. This value can be determined by projecting light through a segment of cloth on a larger screen and actually measuring the total area and the area through which light passes.

Seam Strength (ASTM-1683): Seam strength is a tensile test to determine the strength of a sewed seam in pounds per inch (typically 1-inch square jaws and a travel rate of 12 inches per minute).

Seepage Gradient: Same as hydraulic gradient, the ratio of hydraulic head loss to length of flow path.

Strip Test (ASTM D-1682-64): A test in which the full width of the specimen is gripped in the clamps (typically 1 inch or wider jaws and a travel rate of 12 inches per minute).

Thickness, mils: The loose thickness of a fabric in 1/1000 of an inch.

Warp: The fiber running parallel to the long axis of the fabric.

Weight, Ounces per Square Yard or Grams per Square Meter: The unit area weight per unit area of a fabric. An approximate conversion is: 1 oz/yd^2 = 35 gm/m^2.

Woven Fabric: Fabric woven from monofilament yarn to provide a uniform pattern with distinct and measureable openings.

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Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads

by

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ABSTRACT

Porous woven and non-woven fabrics have been used in road construction in Region 6 since 1974. The fabrics have been used: 1) as filters for subsurface drainage; 2) separation layers to prevent subgrade soil contamination of base layers; 3) subgrade restraining layers for weak subgrades; 4) earth reinforcement to build retaining walls; 5) erosion control, and 6) water proofing membranes.

A reference notebook titled "Fabrics in Construction" is due for release to Region 6 Forests in June 1977. This notebook contains a description of current practices and the state-of-the-art in the use of fabrics in road construction and maintenance. The notebook defines terminology and lists the key factors involved in each usage, and relates the fabric physical and chemical properties to the intended usage. The notebook also contains appropriate technical literature, manufacturers' literature and cost data on the known available fabrics.

This report highlights the contents of the reference book and discusses the current knowledge for the use of fabrics in low-volume road construction and maintenance. Present and projected uses of the fabric and the most significant physical properties related to these uses are discussed.

Probable future uses and the areas of greatest need for technical knowledge and experience are outlined.

The process for moving a fabric or fabric use from the conception and trial use state into full use with standard specifications and design criteria is described.

CHAPTER 1: INTRODUCTION

INTRODUCTION

The reference notebook was determined to be the only practical way to keep abreast of the rapid developments in the use of fabrics for construction of low-volume roads. The reference notebooks are all numbered and assigned to a responsible user to provide for an automatic distribution of new literature from manufacturers, new technical reports appropriate to the subject, and for modification of the written text describing the uses, design guides and specifications for the various fabrics.

The notebook can be a key element in the process of moving a fabric usage from the conception stage to the full usage stage where cost data, design criteria, and specifications have been developed. The reference notebooks provide the means for keeping Forests advised of the status of any particular fabric or usage based on documentation of experience to answer relevant questions.

It is intended that the use of fabrics be implemented in Region 6 of the Forest Service through the trial use program outlined in Forest Service Manual 7170. Essentially, the trial use program involves four steps: 1) a project proposal outlining the intended use, projected cost and benefits, and proposed monitoring to determine costs and benefits; 2) a report on the construction; 3) a report on the monitoring of the project to determine if it did or did not achieve the original project goals; 4) a final report with recommendations for design guidelines, specifications, and future use of the material. The trial use program is for use with all new materials

and ideas. If followed by everyone using new products or techniques, the trial use program would speed up the process of establishing design and construction criteria and reduce duplication of unsuccessful uses.

Most new products and new ideas go through three distinct phases in moving from the conceptual to the full usage level.

Phase I - Trial Use: First usage to develop design criteria, construction methods, economic feasibility, and specifications. Intensive monitoring, instrumentation and analysis is included in this phase. Actual cost for the project may exceed conventional methods by 100 percent.

Phase II - Special Use: Second usage to determine and evaluate appropriate costs and to test criteria, methods, and specifications developed in Phase I. Second usage is a field usage under a minimum of experimental controls to develop realistic criteria and costs.

Phase III - General Use: Full usage Regionwide in accordance with cost, criteria guidelines, and specifications developed in Phase I and evaluated in Phase II. The projects in Phase III are no longer considered trial use.

All phases may not be utilized or required within the Forest Service, depending upon the adequacy of work by other agencies or individuals. It is anticipated that most of the trial use projects will originate on the Forest with all projects monitored by R.O. Engineering Soils and Materials Group.

The trial use concept is incorporated into the fabrics notebook to permit the Regional Office to provide leadership and direction in the rapid incorporation of economically feasible methods and materials into the Forest Service in Region 6, not to control or limit their usage.

It is important in the design, specification, and use of fabrics to understand the various functions that a fabric may provide in the construction of an engineered facility. In most cases, understanding of the primary function of a fabric for a selected usage will lead directly to those fabric properties which control the success or failure of the installation. Therefore, it is essential that the function for each usage (Chapter) outlined in this notebook be understood.

CONCEPTS

Filtration: Filtration is the process of allowing water to easily escape from a soil unit while retaining the soil in place. The two primary functions of fabric used for filtration are: 1) remove water, and 2) retain soil.

Separation: Separation is the physical process of preventing two dissimilar materials from mixing. The most common usage would be to prevent or minimize the movement of weak subgrade soils into aggregate bases. The primary function is: prevent mixing.

Subgrade Restraint: Subgrade restraint is the process of preventing or reducing soil movement and strain by fabric confinement. The primary function is to: restrain soils (against shear failure at low stress).

Earth Reinforcement: The concept of earth reinforcement involves the use of the fabric to increase the strength of a fabric-soil system. The primary function is: strengthen earth.

Erosion Control: Erosion control is the use of fabrics to: 1) prevent movement of surface soils; 2) remove soil from water on the earth's surface, and 3) use of fabrics to promote soil protecting growth. The primary function is to: prevent surface soil movement.

Water Proofing: The purpose of the fabric is to hold sufficient asphalt or other material within the fabric to provide a flexible waterproof layer and to provide tensile strength to the waterproof layer. The primary functions of the fabric are to: 1) hold waterproof substance, and 2) inpart tensile strength.

Pavement Reinforcement: The pavement reinforcement concept involves the inclusion of a fabric in a pavement system to increase the tensile properties of the pavement and reduce the required thickness of the pavement section. The key function in this usage is: strengthen pavement.

Table 1-1 shows the current status of the use of fabrics in Region 6. Fully documented installations, design guidelines, specifications and cost estimating data are necessary for a material or use to be placed in the "General Use" phase.

TABLE 1-1. Status of Fabrics Use in Construction of Low-Volume Roads in Region 6, April 1977.

Use - Function	PHASE I "Trial Use"	PHASE II "Special Use"	PHASE III "General Use"
Filtration -			
Woven			X
Non-Woven	X	X	
Separation	X	X	
Subgrade Restraint	X	X	
Earth Reinforcement	X	X	
Erosion Control	X	X	
Water Proof Membrane	X	X	
Pavement Reinforcement	X		

CHAPTER 2: FILTRATION

I. INTRODUCTION

Filtration is the process of allowing water to easily escape from a soil unit while retaining the soil in place. The two primary functions of fabric used for filtration are: 1) remove water, and 2) retain soil.

A drainage system must meet two conflicting requirements:

A. Piping Requirement: The pore spaces in drains and filters are in contact with erodable soils and rocks must be small enough to prevent most particles from being washed in or through them.

B. Permeability Requirements: The pore spaces in drains and filters must be large enough to impart sufficient permeability to permit seepage to escape freely and thus provide a high degree of control over seepage forces and hydrostatic pressures (4).

Additionally, successful filters allow a small portion of the finest grains of the protected soil to move into the filter, causing a highly permeable filter to develop adjacent to the graded filter. If the filter allows too many fines to pass, drain rock will plug and become impermeable. The other condition is the filter being too fine and stopping all movement of soil fines may trap the very fine soil at the filter boundary causing surface clogging.

These requirements are difficult and expensive to meet using aggregate filters: a) when small volumes of filter material are involved; b) in remote areas; c) for fine grain soils; d) and with minimum levels of inspection and construction control. Not only are these requirements difficult to meet using aggregate filters, the testing of the soils and design of the filter is expensive in manpower and dollar costs (13).

The high permeability requirement of the filter in a drainage system is often ignored. Most references containing filter criteria discuss briefly that the filter will not clog and will have a higher permeability than the protected soil. Standard plans for road drainage installations often show a narrow trench filled with concrete sand and a perforated pipe, leaving only the depth to be established by the designer.

Harry Cedergren states: "Even the most minimal system designed with the help of the rational methods described will have drainage capabilities hundreds of times greater than those of most pavements that have been built in the last 30 or 40 years. Consequently, when these methods are used, even if rough estimates have to be made of inflows, the resulting systems will usually be at least two orders of magnitude better than those designed without an analysis of discharge needs" (5, pg. 75). The drainage criteria referred to by Mr. Cedergren involves (1) Darcy's law of flow, (2) inflow-outflow concept; outflow capabilities of a drainage system must be at least equal to the inflow from all sources, (3) condition of continuity; outflow capabilities of the system should increase

in the direction of flow, (4) time required for water to flow through pavement-drainage systems and, (5) time required to drain after stop of inflow. Items 4 and 5 apply primarily to pavement drainage.

Graded filters for fine soils and concrete sands shown on "standard plans" usually have low permeabilities. "Standard Plan" drainage aggregates which do have high permeabilities are usually rendered ineffective by clogging. The permeability of graded filters are often too low, limiting the area of influence of the drainage system and the rate of water removal. The writer has seen several projects where subdrains installed to remove ground water have actually decreased slope stability by acting as reservoirs due to inadequate flow capacity.

Figure 2-1 shows the relationship between gradation and permeability for drainage materials. "Filter Materials" shown in Figure 2-1 are representative of the gradations required to protect the clayey and silty soils encountered in the Northwest. Like concrete sand, they have permeabilities of 20 to 100 feet/day.

The "Open Graded Bases" shown have permeabilities of 6,000 to 120,000 feet/day and are compatible with woven filter cloths. The gradation selected for use with filter cloth will depend on commercial availability and permeability requirements of the design.

Installations with graded filters and concrete sand usually require a perforated pipe to rapidly drain the collected water. High permeability open graded aggregates used with plastic filter cloths often have adequate flow capacity to eliminate perforated pipes for the first 30 to 100 feet of normal subdrains. Additionally, the open graded aggregate and plastic filter cloth combination allows the use of thinner and more hydraulically efficient drainage layers.

II. FILTER FABRIC SELECTION CRITERIA

The selection criteria for woven filter cloths (Table 2-1) are well established (2, 3, 13, 28) and generally easier to comply with than the design criteria for aggregate filters (Table 2-2). Unlike the aggregate filters, soil gradation tests will not normally be required to properly apply the design criteria when using the woven plastic filter cloth on low-volume road projects.

Selection criteria for non-woven fabric filters are not well established. The "equivalent opening size" (E.O.S.) (Table 2-4) and percent open area criteria used for selection of woven filter fabrics do not apply to the non-woven fabrics because they generally lack "distinct and measurable openings." A "gradient ratio" (G.R.) test similar to the one developed by B. Dan Marks (27) and used by the Corps of Engineers (28) appears to be applicable to selection of non-woven fabrics for filtration.

The design criteria in Table 2-1 permits the designer to select a woven filter cloth that retains the soil being protected, yet permits drainage and prevents clogging. Open graded aggregates are used with the cloth to rapidly remove the water. Reliable gradation charts similar to Figure 2-1 are available for estimating aggregate permeabilities (4, 5, 6, 8).

Aggregate filters can be either a graded filter meeting the criteria in Table 2-2, or a zoned filter having several layers graded from fine adjacent to the soil to coarse at the perforated pipe. Each layer of the zoned filter is designed to be compatible with adjacent filter zones and/or soil. Filter criteria for woven filter cloths are based on the "equivalent opening size" (E.O.S.) and "percent open area."

The gradient ratio is the ratio of the hydraulic gradient over the fabric and the one inch of soil immediately next to the fabric, to the hydraulic gradient over the two inches of soil between one and three inches above the fabric (i_s).

$$G.R. = \frac{i_f}{i_s} \qquad \text{(Eq 2-1)}$$

If the fine particles in the soil adjacent to the fabric get trapped in or on the fabric (clogging), the gradient ratio will increase. Likewise, if the fine soil particles move through the filter cloth (piping), the gradient ratio will decrease.

The Corps of Engineers recommend that the gradient ratio, described in Table 2-3, should not exceed 3. A review of Marks' report (27) indicates the gradient ratio test needs to be continued until the

gradient ratio becomes constant, typically ten days but as long as three to four weeks. Additionally, the gradient ratio test should be performed under intermittent flow conditions representative of fluctuations in the water table or seepage quantities. We recommend against using non-woven fabric filters in critical locations and severe seepage conditions as discussed in the next section.

Cloths tested by the Corps of Engineers which meet the current Forest Service specifications for woven plastic filter cloth are listed in Table 2-5. The physical and strength requirements of the specification are shown in Tables 2-6 and 2-7, respectively (10). This specification is based on the Corps of Engineers' 1972 Guide Specification. Table 2-8 lists the requirements listed in the current (1976 draft copy) Guide Specification. Filter fabrics, woven or non-woven, should comply with one of the sets of requirements (1972 or 1976).

Aggregate used with filter cloth should be as open graded as possible to rapidly remove collected water. Reliable gradation charts such as Figure 2-1 are available for estimating aggregate permeabilities.

Before plastic filter cloth, materials engineering people were stressing the importance of properly graded filters and the futility of "French drains" constructed of uniform large aggregate. Plastic filter cloth will allow the "French drain" to function. In fact, the use of open graded aggregates with plastic filter cloth must now

be stressed to take full advantage of the filtration function of the cloth and maximize the water-carrying capacity of the drainage aggregate.

III. NON-WOVEN FABRICS AS FILTERS

A brief discussion of the background for development of design criteria and specifications for fabric filter systems is appropriate. During 1971 and 1972 the Army Engineers' Waterways Experiment Station at Vicksburg (2) determined the physical, chemical, and engineering properties of seven commercially available plastic filter cloths to develop specifications and design criteria. Six of the fabrics were woven and one was a needle-punched non-woven. The test information and information from 46 projects where filter cloth was used and ten projects where filter cloth was planned to be used were the basis for their initial guide specification (9). Non-woven fabrics were not permitted in the original guide specification due to the lack of distinct openings and apparent clogging during testing of the sample tested.

B. Dan Marks reported in 1975 on his testing of the behavior of aggregate and fabric filters for subdrains (27). His work included an extensive literature review, discussion of the behavior of filters and comparison of laboratory performance of fabric and aggregate filters. The study did not evaluate field installations. The testing included four variations of a non-woven fabric and one woven fabric (provided by the project sponsor), two graded aggregate filters, and 15 soil types developed by processing and recombining

fractions of several natural soils. Based on gradient ratio tests and soil loss into the filters, he concluded that the fabric filter systems investigated performed as well as the aggregate filter systems for all protected soils.

The Corps of Engineers modified their guide specification (28) in 1976 to permit use of non-woven fabric filters when the gradient ratio test and physical property requirements were met. They also reported the "equivalent opening size" (E.O.S.) of the fabrics tested (Table 2-4) before making the guide specification changes. The unpublished testing of non-woven fabrics was not as extensive as that performed previously on woven fabrics.

The E.O.S. and percent open area tests, developed for designing and specifying woven fabric filter systems, do not appear appropriate for non-woven filter systems. For woven fabrics, these properties are directly measureable, predictable, and locked into the fabric during the weaving and calendering process. Non-woven fabrics are manufactured by extrusion and random orientation of fibers in the fabric. The resulting E.O.S. and percent open area of the non-woven fabrics is variable and fixed in the fabric to varying degrees, depending on the fabric weight and the process used to bond the fibers together (hot pressed or needle-punched).

Due to the manufacturing process and their generally higher elongation under load, the apparent E.O.S. of non-woven fabrics will be more variable and more subject to change under load than for the woven fabrics. These tests are clearly inappropriate for the heavier fabrics where no distinct openings through the fabric are visible.

A modification of the gradient ratio (G.R.) test appears more suitable for evaluating non-woven fabric filters. The currently used gradient ratio test should be modified to represent the range of varying seepage rates and fabric strains (enlargement of fabric openings) anticipated in the field. The gradient ratio test has not been confirmed by monitoring field performance.

Testing by others indicates that the non-woven fabrics can perform as effective filter systems. However, it is recommended that the use of non-woven fabrics for filtration be limited to the <u>less critical</u> and <u>less severe</u> filtration projects at this time. This recommendation is based on the uncertainty of the design and specification criteria, the variability of the fabrics, the necessary testing with the protected soil, the cost of the fabric, the cost of potential failure, and the amount of risk involved in using the fabrics. We feel that the woven fabrics can be installed using the established criteria with a greater than 95% success ratio. Success ratio using the non-wovens will be lower unless a gradient ratio type test is perfected and used.

A definition of critical and severe conditions is in order:

Critical: Projects where failure of the filter could result in failure of an expensive or environmentally sensitive portion of a project.

Example - 1) rock blankets greater than or equal to 3-foot horizontal thickness,
- 2) retaining structure,
- 3) road fill greater than 10 feet in height,
- 4) underdrain trenches greater than five feet in depth,
- 5) bridge repair.

Less Critical: Project where failure of the filter would lead to a decreased effectiveness of the system or damage to a limited portion of a project, and which is accessible for repair.

Example - 1) rock blanket less than 3 feet horizontal thickness, and
- 2) filter for drainage of water out of an open graded roadway base.

Severe: Conditions of moderate to high seepage out of erodable soils. A hydraulic gradient is evident moving from the soil toward the filter.

Example - 1) spring areas,
- 2) soils with flowing groundwater,
- 3) soils with a high hydraulic pressure.

Less Severe: Areas of casual seepage where the water entering the system comes primarily from surface infiltration rather than seeping groundwater under hydraulic gradient.

Example - 1) underdrains for an open graded base project with a low groundwater level,

- 2) removal of surface infiltrated water in parking areas and agricultural fields.

The recommendations for when and where to use the non-woven and woven fabrics in the filtration process are based on engineering judgment. More specific design criteria need to be developed and confirmed through laboratory and field testing to guide in selecting the lowest cost fabric consistent with the filtration function and risk. The lower material cost of the lightweight non-woven fabrics for critical or severe seepage conditions appear to be outweighed by the risk and consequence of possible failure at this time.

IV. Construction Practices

For maximum benefit, the plastic filter cloth is placed between the soil and drain rock. The commercially avaiable fabric-wrapped perforated pipes are not suitable for most engineering installations because: (1) the fabric does not meet the design criteria discussed in this paper, and (2) fabric placed around the pipe does not protect the granular drain rock.

Drain rock used with the plastic filter cloth can be from pea gravel to riprap size, as long as the cloth is protected from

damage during construction. During construction the fabric is placed loosely so it will not be stretched during loading. Placement of riprap-sized material may need a granular cushion to prevent damage to the cloth.

Plastic filter cloth is suitable for use in subdrainage trenches, blankets, behind rock buttresses, under riprap, around piezometers, around vertical gravel drains and many other applications where graded filters are normally used. The high abrasion resistant cloths (Table 2-5) should be specified for abrasive applications such as under river or lake shore riprap.

Figure 2-2 shows some typical details for installation of plastic filter cloths. Vertical rock drains with horizontal drain outlets have been used successfully to remove groundwater in the layered glacial sands and silts in Seattle, Washington. Vertical rock drains protected by plastic filter cloth (Figure 2-2f) can be installed placing gravel in cloth tubes inserted in hollow stem augers or cased drill holes. Photographs of actual installations are shown in Figures 2-3, 2-4, and 2-5.

For graded filters, it is well established that close control is required in the production, handling, and placement of the materials, because even a single improperly constructed portion of a filter can lead to failure (4, 27). The filtration properties of filter fabrics are "built in" in the factory and calendered to prevent enlarging of the openings in the field.

Field experiments and accelerated weathering tests (1, 2, 3, 7) have shown that the plastic filter cloths retain their strength after long periods of exposure to fresh and salt water. Stones weighing 150 to 200 pounds have been dropped on loose woven fabric from heights of 2.5 to 4.5 feet without damaging the fabric (2), indicating little danger of damaging the fabric during rock placement. Unlike graded aggregate filters, the condition of plastic filters can be determined visually after installation and before placement of drain rock.

V. Costs and Reliability

Woven plastic filter material costs are $0.12 per square foot delivered, and the non-wovens are $0.06 to $0.25 per square foot, depending on the cloth specified, and the quantity. Installation costs are $0.07 to $0.25 per square foot, depending on difficulty of the project and the experience of the Contractor. Drain rock manufactured during the crushing or screening process (i.e. material retained on the 3/8 or 1/2 inch screen) will cost little more than the base or surface rock being produced.

Two or three separate filter gradations per mile are normal for Forest Service roads built in western Oregon and Washington. Aggregate gradations designed to protect the soils encountered are often "bastard" gradations, not satisfied by any of our rock gradations or gradations available from local aggregate or concrete plants. When available, the aggregate filter costs

range from $6.00 to more than $30.00 per cubic yard (11). In addition to aggregate costs, soil sampling, testing, and filter design costs will exceed $100.00 per soil change.

First cost of subdrains using woven plastic filter cloth, open graded aggregate, and perforated pipe often appear higher than installations without the filter cloth. Subdrainage costs must also include the feasibility of matching the filter to the soil and obtaining and installing the designed filter without contamination or segregation. Graded aggregate filter installations on Forest Service projects probably have less than a 50 percent chance of functioning properly. The chances of success have been necessarily low because of frequently changing soil conditions, nonavailability of specified gradations, and limited sampling, testing, and inspection capabilities. Installations using woven plastic filter cloth should have a success rate near 100 percent, even with limited testing and inspection.

Soil sampling and testing cost will be very low when using woven filter fabrics meeting current Forest Service specifications. Woven fabrics having a 70 to 100 E.O.S. will satisfy the design requirements, for most projects, with the 30 to 70 E.O.S. size required only when coarse sands and gravels with high flow potential are encountered. For non-woven fabrics, soil sampling and testing costs to perform gradient ratio tests for each soil change and several fabrics may exceed $100 per soil change.

VI. Summary

Soil engineers have long known that effective permanent groundwater drainage requires a highly permeable filter and drainage system that rapidly collects and removes water without clogging. Although adequate design criteria have been available for over 25 years, most drainage installations have been a compromise with the ideal due primarily to the cost of sampling, testing, and design of filters to match rapidly changing soil gradations and to the difficulty of procuring and installing the designed filters. The resulting installations often fail due to plugging, clogging, or have inadequate permeabilities to rapidly remove the collected water.

Plastic filter cloths discussed in this chapter are available in a range of E.O.S. to filter a wide range of soils without clogging. Commercially available open graded aggregates are used with the cloth to provide an economical and hydraulically efficient drainage system. Criteria are presented to guide the user in designing and constructing highly reliable drainage systems.

Additional testing is needed to develop design criteria and specifications for the use of non-woven fabrics for filters.

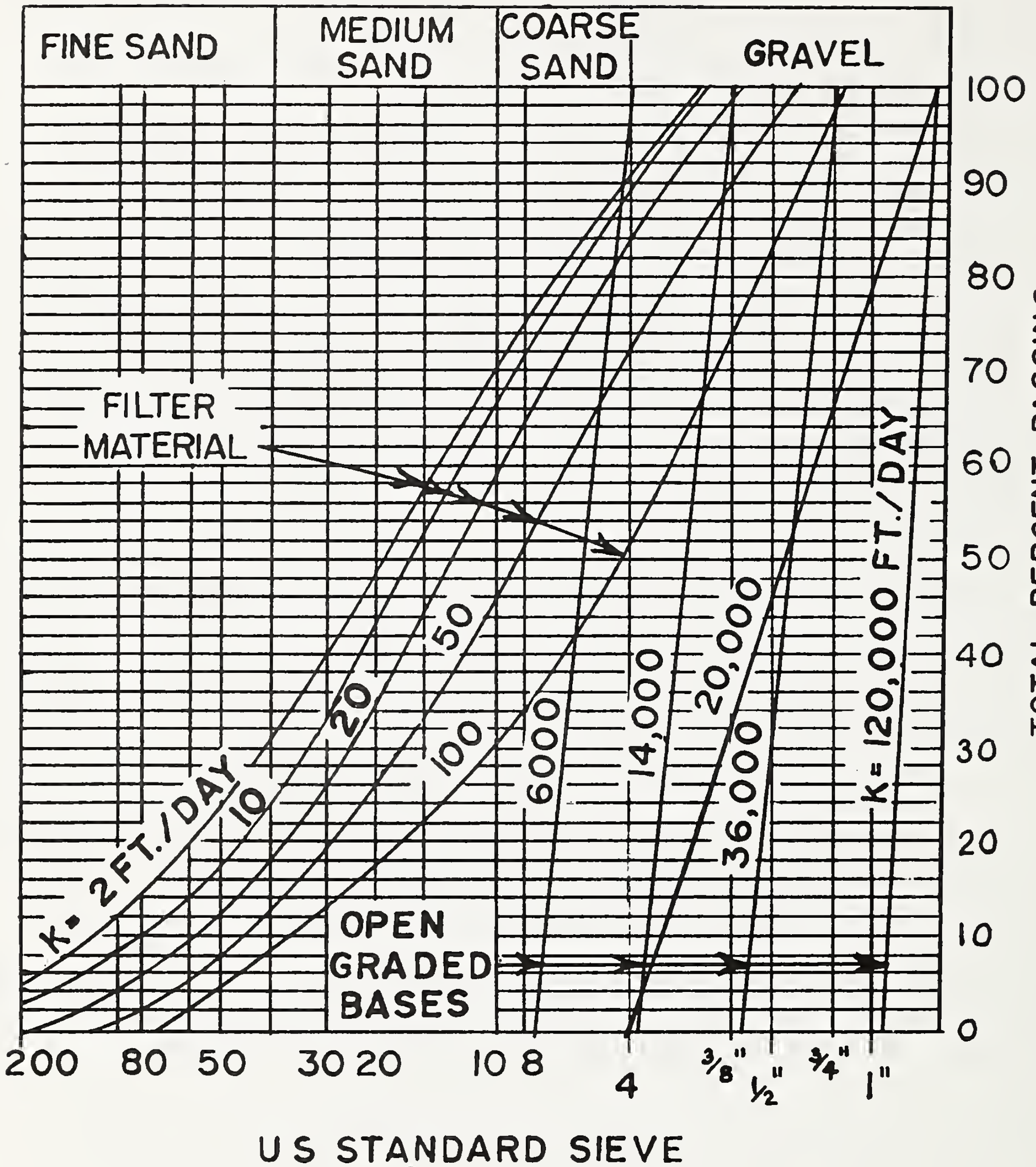
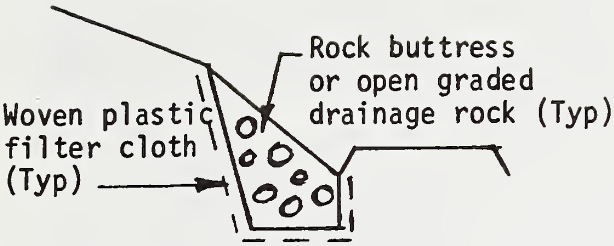
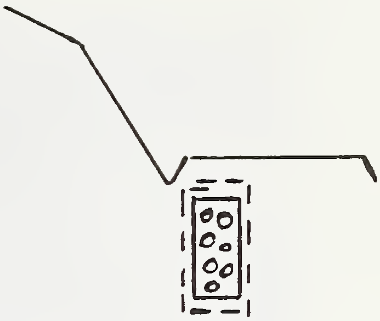


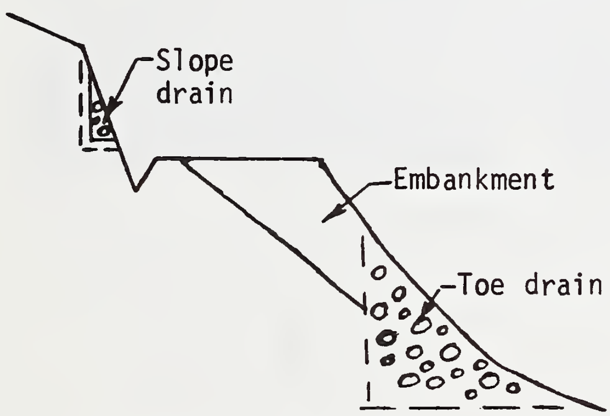
Figure 2-1: Typical Gradations and Permeabilities of Several Open-graded Aggregates and Several Filter Materials. (5,6)



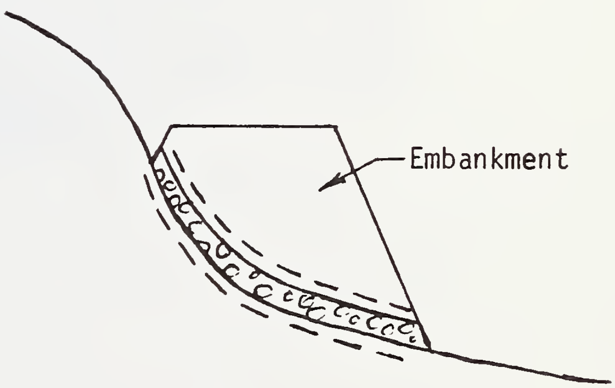
a. Rock Buttress



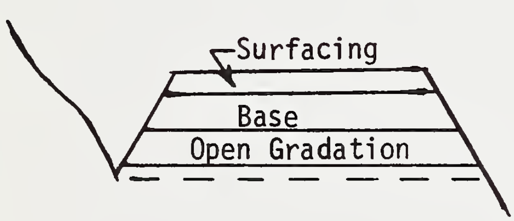
b. Subdrain



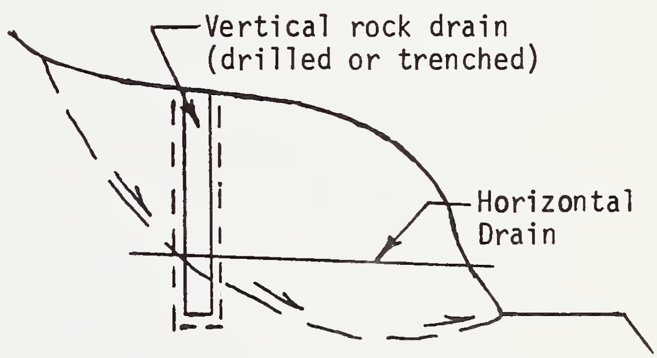
c. Slope and Toe Drains



d. Drainage Blanket



e. Subgrade Seepage



f. Landslide Drainage

Figure 2-2: Typical Plastic Filter Cloth Installations

FIGURE 2-3 Woven plastic filter cloth installed in an excavated trench.

FIGURE 2-4 Subdrainage trench with woven plastic filter cloth, open graded aggregate and perforated pipe nearing completion.

FIGURE 2-5 Drainage blanket to control seepage under a high earth fill.

a. Excavation.

b. Installation.

Table 2-1: Requirements for Filter Cloth (9, 13, 28)

Equivalent sieve opening and percent open area for filter cloth should be based on the following criteria:

a. Filter cloth adjacent to granular materials containing 50 percent or less by weight fines (minus No. 200 material):

$$\frac{\text{85 percent size of soil (mm)}}{\text{opening size of EOS (mm)}} \geq 1.0$$

b. Filter cloths adjacent to all other type soils:

(1) EOS no larger than the openings in the U. S. Standard Sieve No. 70 (0.0083 in.).

Notes: To reduce the chance of the cloth clogging, no cloth should be specified with an open area less than four percent or an EOS with openings smaller than the openings of a U. S. Standard Sieve No. 100 (0.0059 in.). When possible, it is preferable to specify a cloth with openings as large as allowable by the criteria. The Corps of Engineers (28) recommend filter fabrics not be used for soils with 85 percent smaller than the No. 200 sieve. Gradient ratio or other testing should be performed for this case.

For soils ranging in gradation from about one inch size or large to material passing the No. 200 sieve, use only the gradation of the material passing the No. 4 sieve for designing the filter.

Marks recommends careful soil analysis and permeability testing before using fabrics with soils having: 1) liquid limit values greater than 40 percent, and 2) plasticity index values greater than 15 percent.

Table 2-2: Requirements for Filter Materials (12)

Character of Filter Materials	Ratio R 50	Ratio R15
Uniform grain-size distribution (U = 3 to 4)	5 to 10	
Well graded to poorly graded (non-uniform): subrounded grains	12 to 58	12 to 40
Well graded to poorly graded (non-uniform); angular particles	9 to 30	6 to 18

$$R\ 50 = \frac{\text{D 50 of filter material}}{\text{D 50 of material to be protected}} \qquad R\ 15 = \frac{\text{D 15 of filter material}}{\text{D 15 of material to be protected}}$$

Notes: If the material to be protected ranges from gravel (over 10% larger than No. 4 sieve) to silt (over 10% passing No. 200), limits should be based on fraction passing No. 4. Maximum size of filter material should not exceed 3 in. Filters should contain not over 5% passing No. 200. Grain-size curves (semi-logarithmic plot) of filter and of material to be protected should be approximately parallel in finer range of sizes.

Table 2-3: Determination of Gradient Ratio (28)

A permeability test shall be performed in accordance with EM 1110-2-1906, Appendix VII, with the following modifications:

1. The soil specimen shall be 5 inches in diameter and 4 inches in height. It shall consist of the soil that is to be protected in the field by the fabric.
2. A piece of hardware cloth with 1/4-inch openings shall be placed beneath the filter fabric specimen to support it. The fabric and the hardware cloth shall be clamped between flanges so that no soil nor water can pass around the edges of the cloth.
3. Piezometer taps shall be placed one inch below the fabric, and 1, 2 and 3 inches above the fabric.
4. Tap water shall be permeated through the specimen under a constant head loss for a continuous period of 24 hours. The tailwater level shall be above the top of the soil specimen. The gradient ratio shall be determined from the readings taken at the end of the 24-hour period.
5. The gradient ratio is the ratio of the hydraulic gradient over the fabric and the one inch of soil immediately next to the fabric, (i_f), to the hydraulic gradient over the two inches of soil between one and three inches above the fabric (i_s).

$$G.R. = \frac{i_f}{i_s}$$

Table 2-4: Determination of Equivalent Opening Size (EOS) (28)

Five unaged fabric samples shall be tested. Obtain 50 gm of each of the following fractions of standard glass beads:

	U. S. Standard Sieve Number				
Designated EOS	Passing	Retained On	Designated EOS	Passing	Retained On
20	18	20	70	60	70
30	25	30	100	80	100
40	35	40			
50	45	50			

Suitable glass beads can be obtained from:

Cataphone Division
Ferro Corporation
P. O. Box 2369
Jackson, Mississippi 39205
Telephone: (601) 939-4631

Within each size range, 98% of the beads should be within the specified range. The fabric shall be affixed to a standard sieve 8 inches in diameter having openings larger than the largest beads to be used in the test. The fabric shall be attached to the sieve in such a manner that no beads can pass between the fabric and the sieve wall. Shaking shall be accomplished as described in paragraph 2d (1) (g), Appendix V, EM 1110-2-1906, except the times for shaking shall be 20 minutes. Determine by sieving (using successively coarser fractions) that size of beads of which five percent or less by weight passes through the fabric; the equivalent opening size, EOS of the fabric sample is the "retained on" U. S. Standard Sieve Number of this fraction. The "equivalent opening size" of some fabrics

Table 2-4 (cont'd)

tested at the U. S. Army Engineer Waterways Experiment Station are as follows:

Fabric	EOS (Sieve No.)
Filter X	100
Laurel Erosion Control Cloth	100
Mirafi 140	100
Monsanto E2B	80
Nicolon 66411	30
Nicolon 66429	40
Polyfilter GB	40
Polyfilter-X	70

Table 2-5: Cloths Tested by Corps of Engineers that Comply with Forest Service Specification 6-47 (10)

Manufacturer or Fabricator	Trade Name	E.O.S. Sieve No.	Percent Open Area	Abrasion Resistance
Carthage Mills, Inc.	Filter X	100	4.6	Low
Erosion Control Div.	Poly-Filter X	70	5.2	High
Cincinnatti, OH 45216	Poly-Filter GB	40	24.4	High
Advance Construction Specialities Co. P. O. Box 17212 Memphis, TN 38117	Erosion Control Fabric (Type I)	100	4.3	High
Erco Systems, Inc. P. O. Box 4133 New Orleans, LA 70118	Nicolon 66411	30	36.0	Low

Notes: E.O.S. is "equivalent opening size," and is defined as the number of the U. S. Standard Sieve having openings closest in size to the filter cloth opening.

"Percent open area" is defined as the summation of the open areas divided by the total area of the filter cloth.

For "High" Abrasion Resistance, the strength loss after testing shall not exceed 70 percent and the abraded strength must be no less than 100 lbs. in the stronger principal direction and 55 lbs. in the weaker principal direction.

Table 2-6: Minimum Physical Requirements for Plastic Filter Cloth (10)

Test	Minimum Strength % of Unaged Tensile Strength
Alkali Treatment	90
Acid Treatment	90
Low Temperature Treatment	85
High Temperature Treatment	80
Oxygen Pressure Treatment	90
Freeze Thaw	90
Weatherometer	65
	Test Result
Brittleness	No failures at -60^{o} F.
Weight Change in Water	Less than 1.0%

Table 2-7: Minimum Unaged Strength Requirements for Plastic Filter Cloth (10)

Cloth Type	Pretested Cloths	Stronger Principal Direction (Tensile, Lb.)	Weaker Principal Direction (Tensile, Lb.)	Burst (PSI)	Puncture (Lb.)	Seam Breaking (Lb.)
AB	Poly-Filter X Poly-Filter GB Erosion Control Fabric	200	200	510	125	195
C	Nicolon 66411	180	100	250	65	90

Table 2-8: Current Corps of Engineers' Physical Strength Requirements (28)

Physical Property	Test Procedure	**Acceptable Test Results
Tensile Strength + (Unaged Fabric)	ASTM D-1682 Grab Test Method using 1 square inch jaws and a travel rate of 12 inches per minute.	200 pound minimum in any principle dirction.
Bursting Strength + (Unaged Fabric)	ASTM D-751 Diaphragm Bursting Tester	500 psi minimum.
Puncture Strength + (Unaged Fabric)	ASTM D-751 Tension Testing Machine with Ring Clamp; steel ball replaced with a 5/16-inch diameter solid steel cylinder centered within the ring clamp.	120 pound minimum.
Abrasion Resistance	ASTM D-1682 as above, after abraded as in ASTM D-1175 Rotary Platform, Double Head Method: rubber-base abrasive wheels equal to CS-17 "Calibrase" by Taber Instrument Co.; 1 kilogram load per wheel; 1000 revolutions.	55 pound minimum in any principle direction.
Seams	ASTM D-1683 Seam Breaking Strength.	Not less than 90% of the unaged fabric tensile strength in any principle direction.

** Acceptable test results strengths may be reduced 50 percent for fabric to be used in drainage trenches, beneath concrete slabs or to be cushioned from rock placement by a layer of sand or by zero drop height.

+ Unaged fabric is defined as fabric in the condition received from the manufacturer or distributor.

CHAPTER 3: SEPARATION

The concept of separation is a physical process of preventing two dissimilar materials from mixing. The most common usage would be to prevent or minimize the movement of weak subgrade soils into aggregate bases. The primary function is: prevent mixing.

The objective of subgrade and base separation can be achieved several ways besides the use of fabrics. Depending on the soil type, sand blankets, properly graded bases, thicker sub-bases, and lime and Portland cement treated subgrades have proven cost effective. The sand blanket and graded base prevent contamination by use of the aggregate filter criteria (Table 2-5). Thicker sub-bases are used when a low cost material is available. If six inches of contamination is anticipated, then six inches of sub-base material should be included in the project in addition to the calculated structural requirements. The lime and Portland cement treatment process is effective in two ways; first it reduces the rate and amount of contamination of the base and second, it granulates the fine soil particles making them relatively harmless to the strength of the base. The lime and portland cement method may prove to be the most cost effective methods for treating contaminated aggregates on existing roads, and should always be considered as an alternative to the use of fabrics for separation.

The process of subgrade contamination of the base can be readily observed on any existing road by excavating test holes through the base and subgrade. The extent and rate of intrusion and contamination depends primarily on the soil and base gradations, construction process, moisture conditions, and traffic.

It is not uncommong to observe four to eight inches of base contamination for roads in Region 6. It only takes about 20% by weight of subgrade soil mixed into the dense graded bases to reduce their bearing capacity to that of the soil (14). Figure 3-1 illustrates the total aggregate thickness required to serve the same traffic with and without base contamination. When contaminated by clay or silty soils, aggregate base will change from an initial CBR of 80 (a value = 0.13) to a CBR value of about 15 (a value = 0.09) (15). For this example, 2.5 inches of additional dense graded base is required in the contaminated section to obtain the same structural capacity as a section without contamination. The value of the separation layer is equal to the cost associated with the additional base.

The information required to determine the cost effectiveness of fabrics or other separation layers is: a) the amount of contamination for the design without separation layer; b) the amount of contamination with a separation layer, and c) the cost of the separation layer compared to the cost of the additional thickness required to account for the contamination. Information on the amount of contamination to expect on a project without fabrics can be gained by test excavations in existing roads in areas with similar construction, soil and traffic conditions.

Currently, the amount of contamination a separation layer will prevent cannot be estimated due to a lack of documented field and laboratory testing. Until further documentation is made we recommend fabric separation installations be designed on the basis of elimination of 75% of the contamination by use of fabrics and 100% of the elimination using lime or Portland cement treatment.

The following procedure is for estimating the cost effectiveness (appropriateness) of fabric as a separation layer:

1. Estimate the thickness of the contaminated zone by making test excavations in existing roads with similar construction, soils, and traffic to the project being designed.

2. Assign a structural value ("a" value) to the contaminated and uncontaminated layers (15).

3. Calculate the thickness of the structural section required with and without contamination.

4. The structural cost of the contamination is equal to the difference in thickness between the structural systems with and without contamination.

5. The conventional design without fabrics should include additional thickness required by the contamination, with the additional thickness being sub-base or base material (either is suitable since this layer will be contaminated to some low bearing capacity).

6. The fabric separation design should assume the fabric will prevent 75% of the contamination. Therefore, the fabric section would consist of the fabric plus the 25% of the additional sub-base or base due to contaimination without fabric plus the originally designed structural section.

7. A cost analysis of the systems with and without the separation layer (comparison of structural sections in 5 and 6 above) will assist in the decision on the cost effectiveness of the use of fabrics.

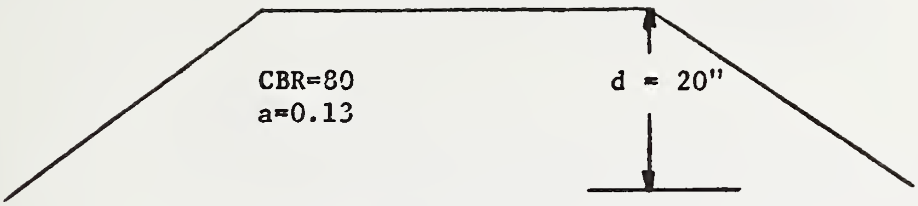
8. Compare the cost of preventing contamination by adding lime or Portland cement to the subgrade.

FUTURE STUDY NEEDS

The unknown in the use of the separation layers at present is the amount of contamination to expect on a road with and without the separation layer. Information on the amount of contamination without a separation layer can best be determined by performing test excavations in existing roads.

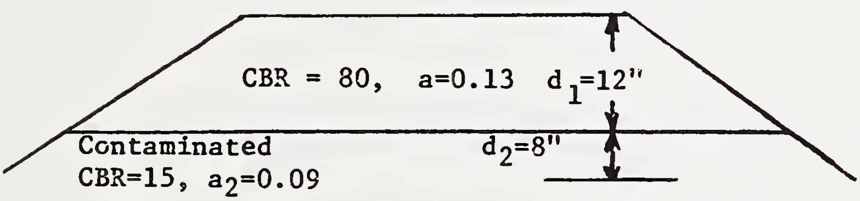
The long-term answers to the amount of contamination with and without fabric or other separation layers can best be determined by trial use projects where the contamination is monitored over a period of time. An alternative way to determining the amount of contamination to expect with and without fabrics would be through dynamic laboratory tests of base, fabric, and subgrade systems with and without fabrics.

The trial use installations could determine system costs and establish design, construction and cost values for field use. The laboratory testing could rapidly establish approximate ratios of contamination values in a short period of time to provide initial guidance.



structural number
sn = ad
sn = 2.60

a.) As Constructed



$sn = a_1 d_1 + a_2 d_2$
$sn = 2.28$
sn Difficiency
$= 2.60-2.28=0.32$
Additional Base Required
$\frac{0.32}{0.13} = 2.5''$

b.) Contaminated

Figure 3-1 - Example Calculation for Additional Base Required due to contamination from poor subgrade.

CHAPTER 4: SUBGRADE RESTRAINT

I. INTRODUCTION

Subgrade restraint is the process or concept of preventing or reducing soil movement and soil strain by use of fabrics for confinement. The primary function is: restrain soils (against shear failure at low stresses). The term subgrade restraint is used instead of the term subgrade reinforcement because: a) it better describes the process of the soil and fabric interaction which gives the apparent increase to the soil bearing capacity, and b) to avoid the possible misconception that the fabric itself strengthens a soil. In the Forest Service, the term subgrade reinforcement is normally associated with the addition of pit run rock material to support vehicles.

The subgrade restraint mechanism will predominate only for weak soils loaded (stressed) to levels at which the soil would fail or rut without fabrics. The economics of using fabrics to reduce structural thickness based on the restraint mechanism will control only for subgrades with a CBR less than or equal to 2 or 3. For subgrades with CBR greater than 2 or 3, the separation or filtration function will control.

II. THEORY

The restraint mechanism can best be understood by reviewing bearing capacity factors used for footings:

Soil bearing capacity failures normally occur by rupture (general shear) of soil under and adjacent to footings similar to Figure 4-1a. For loose or soft soils, the failure occurs by punching or rutting which is referred to as "local shear," (12). (Figure 4-1b.)

$$q = \frac{\gamma b}{2} N_\gamma + C N_c + q' N_q \qquad \text{(Eq. 4-1)}$$

The term γ is the soil unit weight, the term b is the footing width, C is the soil cohesion, q' is the vertical overburden pressure at the footing level.

The values of N_γ , N_c, and N_q are dimensionless bearing capacity factors that depend only on ϕ and on the shape of the failure zone as assumed by different investigators. Values for these factors as functions of ϕ from the analyses of Terzaghi and Meyerhoff are given in Figure 4-2 (20). ϕ is the angle of internal friction.

For a footing resting on the ground surface and loaded rapidly to failure without permitting drainage, $\phi \gtrsim 0$ and equation 4-1 becomes:

$$q = CN_c \qquad (E_q\ 4\text{-}2)$$

Note: $\phi = 0$ only for saturated low permeable soils under rapid loading such as wheel loads.

The bearing capacity of the footing under this condition depends only on the cohesion of the soil (undrained shear strength) and N_c. N_c from Figure 4-2 for $\emptyset = 0$ is 5.4 to 5.9 for general shear and 3.8 for local shear.

From laboratory model studies using aggregate and fabric over soft soils, Barenberg (16) concluded that the allowable stress on a soft soil under repeated loading could be predicted from E_q 4-2 using the undrained shear strength of the soil for C and bearing capacity factors, N_c, of 3.3 and 6.0. The values of 3.3 and 6 C are the stress level at which deep rutting (greater than 2 inches) will occur with only a small number of loads when fabric and no fabric respectively are used. N_c values of 5.0 and 2.8 C are proposed by writers to be the stress levels, with and without a fabric layer respectively, to which soft subgrades could be stressed without excessive ruts (less than 2 inches). These values are the same order of magnitude as the "general shear" and "local shear" values for footings.

Barenberg constructed a series of curves similar to Figure 4-2 for determining the thickness of material required to reduce the stresses from the wheel loads to the allowable level when roads were constructed with and without fabric. The factors of 3.3 and 6.0 are incorporated in Figure 4-2. Figures 4-3, 4-4 and 4-5 are a similar set of curves developed for single, dual, and dual tandem wheel loading over a board range of loadings. Boussinesq's equation was used for determining the vertical pressure under a circular load applied at the

ground surface. The factors of 2.8, 3.3, 5 and 6.0 C were not incorporated into these curves to minimize the number of curves and to allow adjustment of the factors as more knowledge is gained.

Barenberg also recommended the use of field vane shear and cone penetration devices for determination of soil strengths. Due to a natural wide variation of soil strength in the field, he recommended taking many groups of readings at several locations on a project. The designs soil strength for a group of readings is the soil strength at which not more than 75% of readings are higher.

III. DESIGN PROCEDURE

Naturally ocurring soils have a wide variation in soil strength (16) and failures can be expected to initiate at the weakest soil area and rapidly progress throughout a wide area. It appears appropriate to determine the undrained strength in the field utilizing rapid means to determine the lower limit of soil strength and to design to prevent failure in the weakest soil unit. Based on these considerations, work by Barenberg and the trial use project at Quinault, Washington, we recommend the following procedure for design of low volume roadways using fabrics for subgrade restraint:

A. Visually segment the road into logical construction segments in the field, taking into consideration soil type, vegetation, road grade, terrain slopes, etc.
B. Determine the soil strength in the field using the cone penitrometer (C approximate equal cone value divided by 10 or 11) and/or vane shear (C is read directly).

C. Make the strength determination at 2 or 3 separate places where the soil appears to be the weakest. Make 6 to 10 strength readings at two depths (0-9 inches and 9-18 inches) at each sample site (sample site is approximately 3 feet in diameter).

D. Determine the design strength as the 75th percentile strength for each set of readings at each depth. The 75th percentile is the strength at which 75 percent of the soil strength readings are higher than this value.

E. Determine the maximum single wheel load, maximum dual wheel load, and the maximum dual tandem wheel load anticipated for the road during the design period.

F. Determine the required aggregate thickness from the load-stress depth curves (Figures 4-3, 4, 5) for each maximum loading. Enter the curve with stresses equal to 2.8, 3.3, 5 and 6.0 times the design strength for each depth at each location.

G. Plot the aggregate thickness for each test location to scale by station on a road profile sheet (plot only the greatest aggregate thickness determined from either the shallow or deep strength readings).

H. Show the field determined road segments on the profile. Connect the plotted 75th percentile aggregate thickness readings with straight lines (2.8, 3.3, 5 and 6.0 C).

I. Select the design thickness and design road segments visually from the plot of the aggregate thicknesses. The design depth and design segments should be to the next highest 1-inch thickness. The strengths and aggregate thicknesses can aid in the selection of design road segments.

The significance of the thicknesses determined from the charts using various values of C are:

2.8C is the stress level on the subgrade at which very little rutting will occur under a great amount of traffic (greater than 1000 18K axle equivalencies) without fabric.

3.3 C is the stress level at which a great amount of rutting will occur under a small number of axle loadings (probably less than 100 18K axle equivalencies), without fabric.

5.0 C is the stress level at which very little rutting would be expected to occur at high traffic volumes (greater than 1000 18K equivalency axles) using fabric.

6.0 C is the stress level at which a great amount of rutting will occur under a small number of axle loadings (probably less than 100 18K axle equivalencies) using fabric. A great amount of rutting is considered to be a 4-inch or greater rut. Very little rutting is considered to be less than 2 inches of rutting extending into the subgrade.

Other important points to remember are:

A. If more rutting occurs during construction than was designed for, the thickness should be increased at least as much as the thickness difference between 2.8 C and 3.3 C.

B. Surface deflections at stress levels of 3.3 C without fabric and 6.0 C with fabric will be equal.

C. Roads on very soft soils are usually weakest at the time of construction. The subgrade will tend to gain some strength with time due to consolidation under fill weight and traffic. Subgrade contamination of the fill will be very minor when fabrics are used.

D. The maximum fabric potential and thus the maximum economy is achieved on low standard roads where high deflections and 4- to 6-inch ruts can be tolerated. Design values of 6.0 and 3.3 C, with and without fabric, can be used.

E. If poor quality fill materials are used, the thickness of good quality base and surfacing required to prevent rutting of the poorer material must be designed using standard design methods (15).

F. Fabrics should not be used for subgrade restraint when soil CBR is greater than or equal to ($\geq$)3 (vane shear cohesion 1500 psf and cone penetrometer $\geq$ 120 psi). (CBR-vane-cone relationships can be approximated using Figure 4-2.)

G. Preliminary test results from the Quinault "Trial Use" installation showed that the lightweight non-woven fabrics (4 oz per square yard) performed as well as the heavier (8 to 16 oz per square yard) once they were installed.

H. The above design procedure is applicable only to shallow deposits of soft materials. For deeper deposits settlement of the fill must also be considered. See Vischer (32), and Greenway and Bell (33).

Figure 4-6 is the Special Project Specification being used on several projects in Region 6. The specification is necessarily non-restrictive to determine, through monitoring of these installations, the optimum design specification and construction of these installations.

Minimum fabric strength properties specified in current "Special Use" specifications are:

A. Grab Test, ASTM D-1682 warp and fill (lb/in) = 120 minimum.

B. Weight, (oz/yd^2) = 4.0 minimum.

C. Elongation at failure = 50% minimum.

IV. QUINAULT NON-WOVEN FABRIC TRIAL-USE INSTALLATION

Background: One of the major uses of non-woven fabric is subgrade restraint where road construction must cross areas of low bearing strength (CBR $<$ 3). Generally, areas with a high water table fall in this category, especially when combined with organic and/or fine-grained soils. Peats and muskegs would be good examples of

this type of condition. The test road site has a fine-grained organic soil with water table at the ground surface.

Alternate construction methods include such things as lightweight fills (sawdust), excavation, turnpiking, landing mats, corduroy, plank roads, etc.

Fabric Trial-Use Objectives: Although considerable research has been done and several test sections built in the past year, some questions still remain. We, therefore, made the decision to build the Quinault test section. Briefly, the objectives were:

A. Field check existing design theories and procedures.
B. Determine fabric materials requirement such as thickness, strength, and plastic type.
C. Check installation costs of the various types of fabrics.
D. Determine construction procedures and minimum equipment requirements.
E. Check effect of size of rocks used in fill over the fabric as it relates to fabric damage and minimum fill thickness.

Site Selection: Several things were considered essential in selecting a site:

A. Wanted - a weak subgrade (CBR $<$ 3) with high water table.
   Site - subgrade CBR $<$ 0.1, water table at ground level.
B. Wanted - area currently requiring special construction techniques.

Site - current practices called for clearing with cranes or mats, excavation hauled to waste areas and backfilled with rock hauled from borrow areas.

C. Wanted - interest by field personnel.

   Site - timber purchasers had already tried fabrics and were extremely interested.

D. Wanted - potential for saving money.

   Site - proposal estimated a savings of $5,000 per mile.

Test Sections: The test sections were designed structurally using the design curves shown in Figures 4-3 through 4-5. An effort was made to include all the types and weights of fabrics available from the various suppliers. These are summarized in Table 4-1. Duplicate sections of each fabric along with control sections were laid out and located by the random selection process. Each test and control section was fully instrumented. Records of construction traffic were kept and future traffic data will be collected.

Instrumentation: Three types of data were collected with the instrumentation installed:

A. Settlement was measured at three levels with the aid of settlement plates shown in Figures 4-17 and 4-18. The three levels of measurement were: a) subgrade; b) top of embankment; c) road surface.

B. Strain in the fabric. Figures 4-9 through 4-22 show the type of gage and installation procedure.

C. Vertical pressure cells were installed at various depths in the test section.

D. Traffic counters will be used to count traffic after construction is finished.

Preliminary Conclusion: Settlement occurred rapidly and up to about 6 inches in magnitude. The majority occurred in the first week after placement of the embankment.

No strain has been measured. This was not expected. It may still occur with more traffic. The layer of organic fine soil varies in thickness from 3 to 5 feet. It is underlain with glacial gravel which apparently allows drainage and consolidation without buildup of large horizontal stresses.

The amount of strain is of interest because the various fabrics differ in their strain characteristics. In this case, it does not appear critical.

The fabrics are also available in various thicknesses. Since no strain occurs this does not appear to be critical from a strength criteria. From results of previous research, this was not surprising. Generalizations should not be made regarding settlement and strain based on this project. Other projects have shown other results.

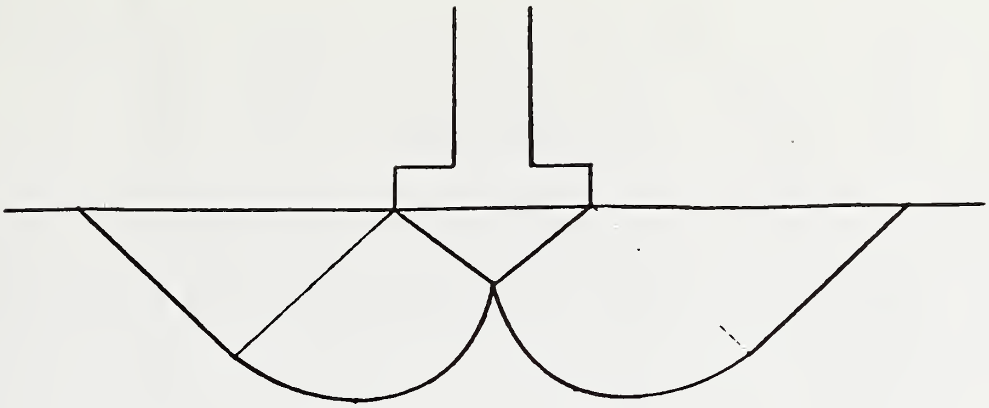
The other concern in regard to thickness is susceptibility to puncture and tearing during construction by dropping rock on it. It was felt that the light (4 oz.) fabrics would be damaged by placing large rock and either rock size or fabric thickness would have to

be controlled. This was not found to be true on this project where rocks as large as 24 inches were used.

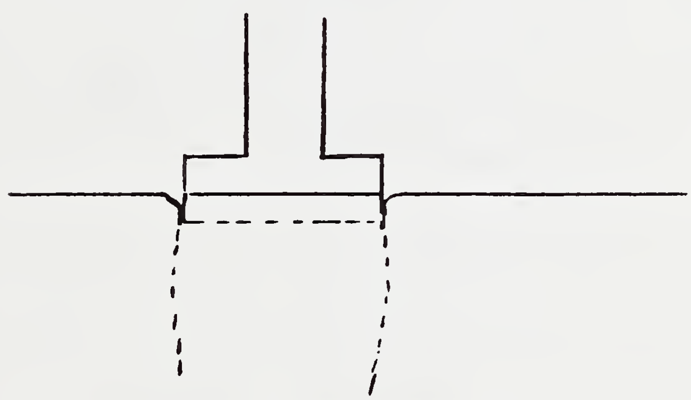
Lift thickness as a function of maximum rock size was a problem. When the lift thickness is less than twice the maximum rock size, it is impossible to spread and level the lift without getting movement at the fabric interface and thus tearing the fabric. Damage generally resulted to all thicknesses of fabric when this movement occurred.

Preliminary data indicates the design procedure used is adequate but hopefully can be refined when all the data is analyzed.

Cost data on other projects in this area using the design and construction procedures developed to date indicate a cost savings of $10,000 per mile of single lane construction can be expected.



a) Failure by general shear



b) Failure by local shear

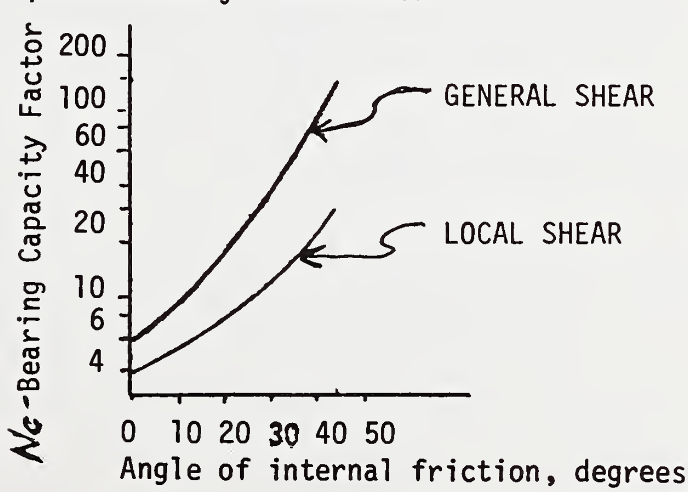


Figure 4-1 - Types of foundation shear failure.

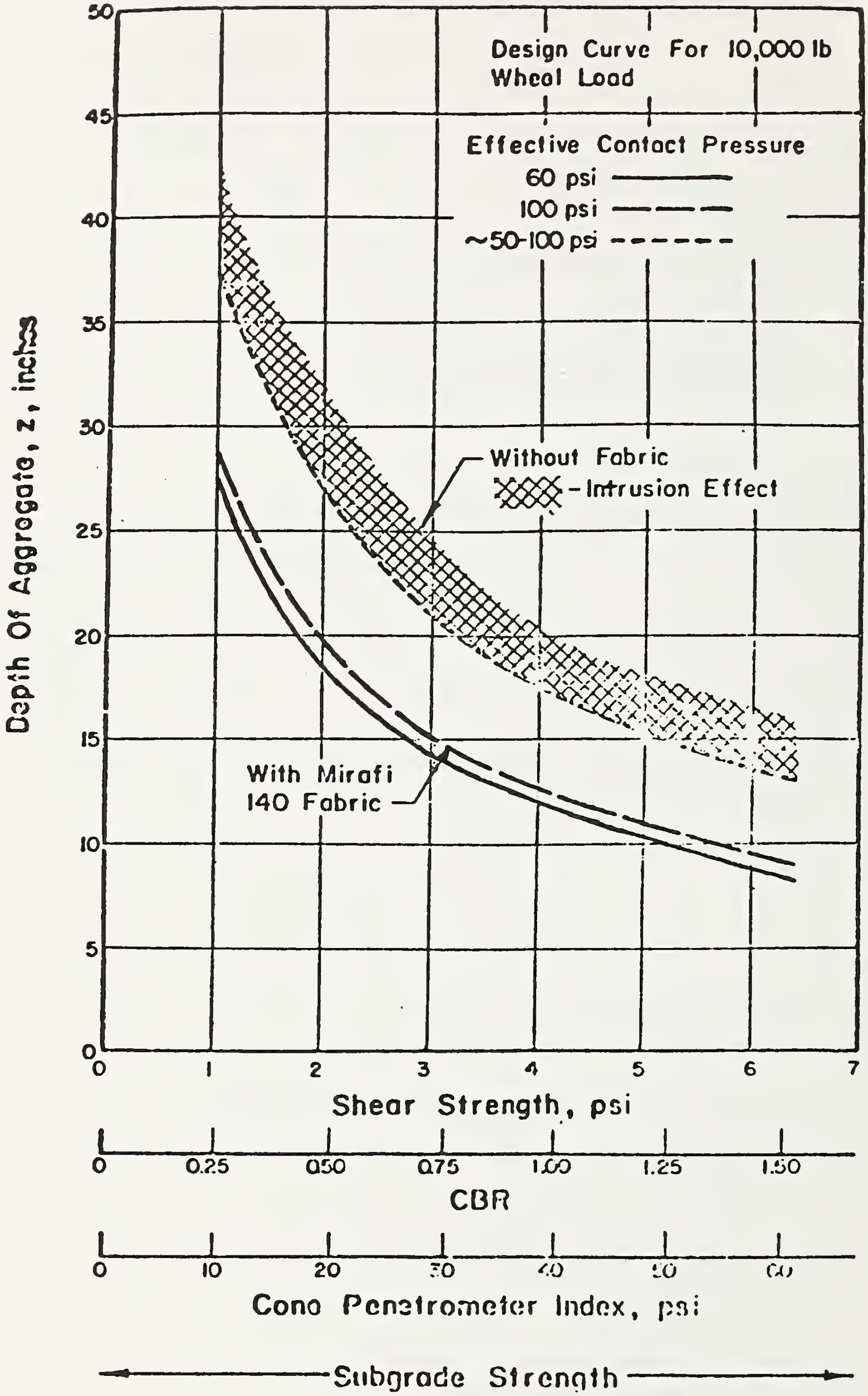


FIGURE 4-2

Thickness Design Curve For 10,000 lb. Wheel Load

(from Barenburg, (16))

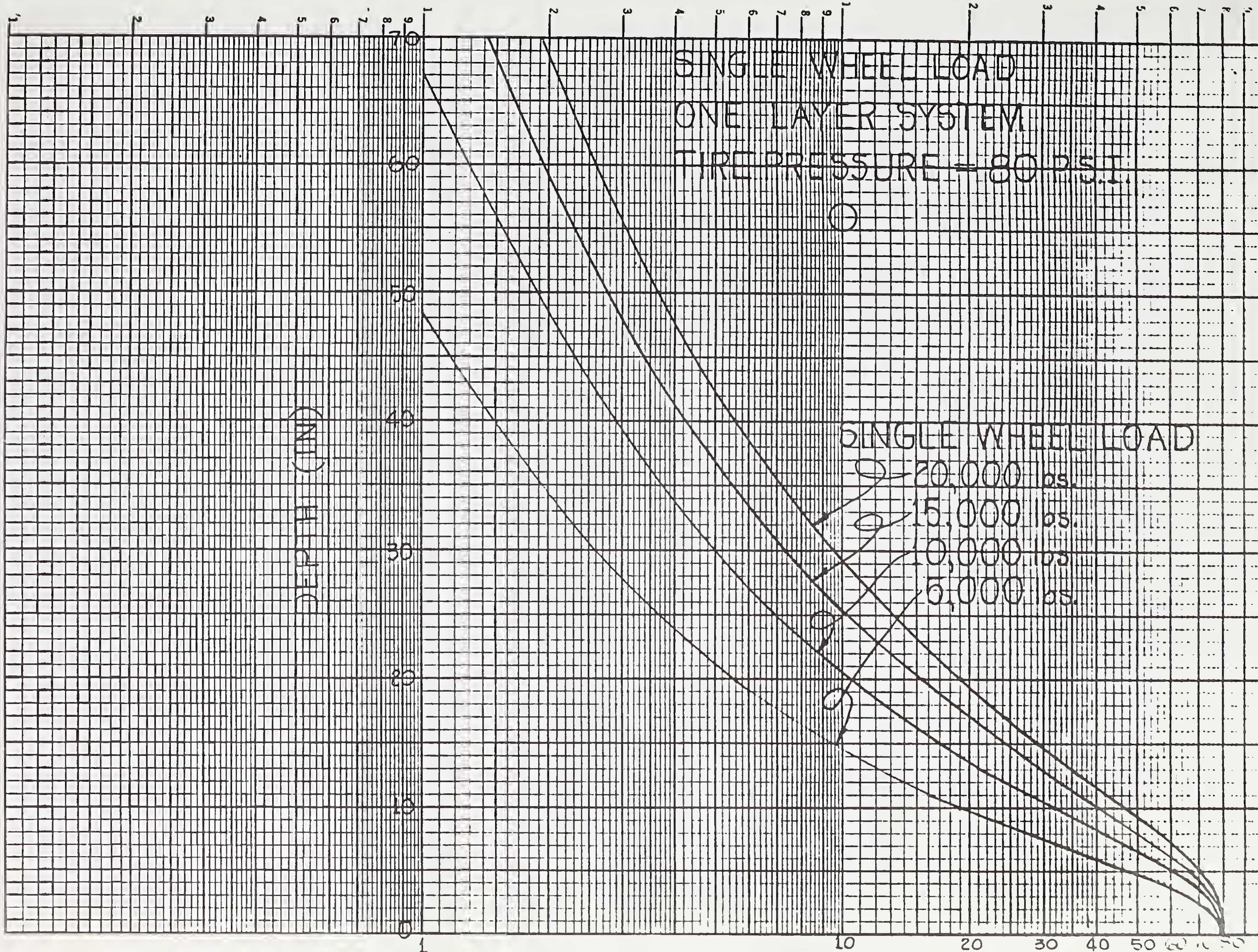


FIGURE 4-3

C Nc, P.S.I.

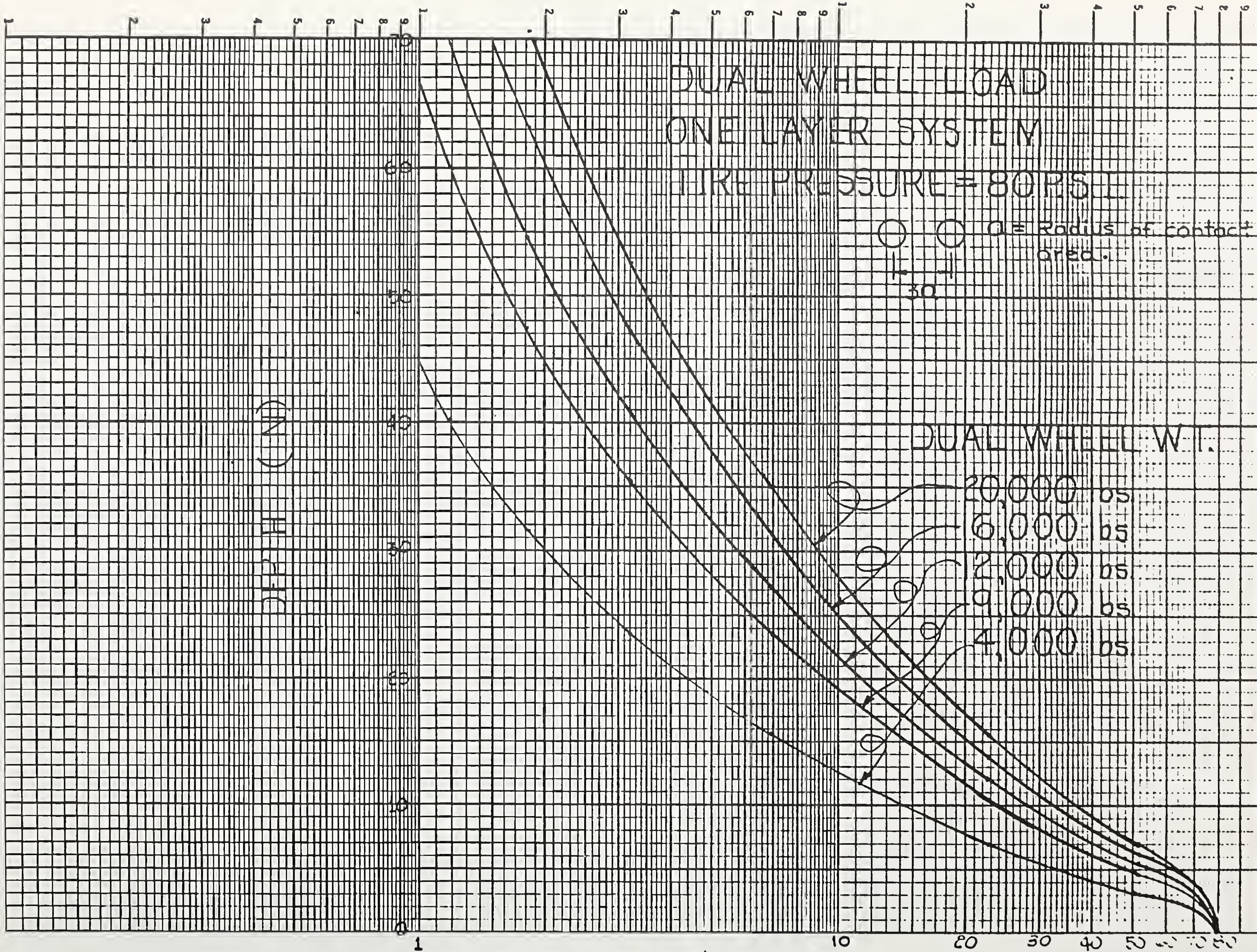

DUAL WHEEL LOAD
ONE LAYER SYSTEM
TIRE PRESSURE = 80 PSI
a = Radius of contact area.
3a
DUAL WHEEL WT.
20,000 lbs
16,000 lbs
12,000 lbs
9,000 lbs
4,000 lbs
C Nc, P.S.I.

FIGURE 4-4

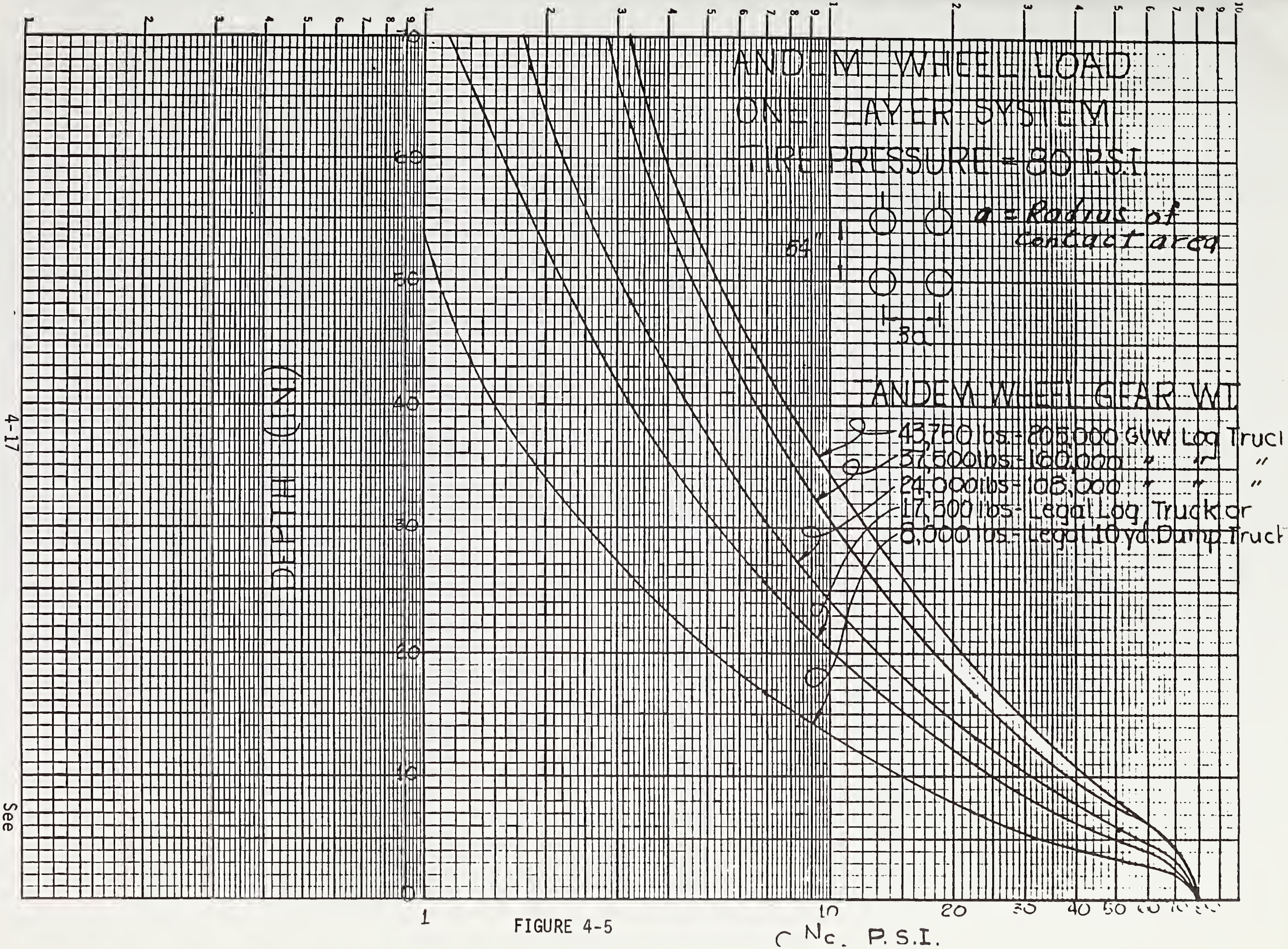


FIGURE 4-5

See

Figure 4-6

SPECIAL PROJECT SPECIFICATION

WEST FORK DAM TIMBER SALE

Non-Woven Fabric

6-2302-a

DESCRIPTION:

1.1 This work shall consist of furnishing and installing a non-woven fabric used in the roadbed design shown on drawings and in accordance with these specifications and in reasonable conformity with the lines and grades established.

MATERIALS:

2.1 The type and weight of fabric shall be as shown on drawings.

CONSTRUCTION REQUIREMENTS:

3.1 Surface Preparation: After clearing has been completed, the ground shall be leveled and smoothed to remove humps and depressions which exceed six inches in height and depth. Small pieces of woody debris shall be removed or pushed below the ground level. Light vegetation (grass, weeds, leaves, and fine woody debris) may be left in place. Roadbed sections with sideslopes greater than ten percent shall be graded in accordance with Specification 30-Roadway Excavation, prior to placement of the fabric.

3.2 Fabric Placement: Fabric shall be installed directly on the prepared surface. Longitudinal and transverse joints shall be overlapped at least three feet.

3.3 Covering Fabric: Borrow or base course material shall be placed to designated thickness in one lift and spread in the direction of fabric overlap. Borrow or base course shall be spread in a manner to fill soft or weak bearing areas. Hauling equipment shall not be operated on the fabric until the total thickness of borrow or base course is placed.

3.4 Patching Fabric: Torn, punctured, or separated sections of the fabric shall be repaired by installing a fabric patch over the hole prior to placing the borrow or base course material. The patch shall be at least three feet larger in horizontal dimensions than the hole to be repaired.

Example Problem:

The shear strength based on the 75th percentile is 3 psi. Legal weight log trucks will be used (Figure 4-5).

a. Using 2.8

   2.8 x 3 = 8.4 psi

   Depth - 22.5 inches (from chart)

b. Using 3.3

   3.3 x 3 = 9.9 psi

   Depth = 20.0 inches (from chart)

c. Using 6

   6 x 3 = 18 psi

   Depth = 13 inches (from chart)

Figure 4-7: Example Problem Using Fabric Restraint Layer

Figure 4-8: Wet, low strength soils which are common in the Quinault, Washington forests.

Figure 4-9: Clearing is accomplished by shovel, often on wood mats. A rubber-tired or tracked dozer would bog down in this area after several passes.

Figure 4-10: Fabric placement. Notice the sticks and uneven subgrade.

Figure 4-11: Fabric placement. Notice the muddy condition of the subgrade.

Figure 4-12: Fabric placement. Notice the rutted subgrade.

Figure 4-13: Fabric placement nearing completion while fill placement proceeds. Notice the 3-foot fabric overlap.

Figure 4-14: Field sewing of fabrics can be used instead of the 3-foot overlap. This was done in all test sections.

Figure 4-15: Fill placement and instrumentation installation at Quinault, Washington. Note the uneven subgrade and wood debris.

Figure 4-16: A completed road section adjacent to the clearing operation.

Figure 4-17: Settlement Plate installation at Quinault.

Figure 4-18: Settlement plate extension rods dug out for reading.

Figure 4-19: Cutting strain gage wires to length during installation.

Figure 4-20: Strain gages prior to installation.

Figure 4-21: Series of strain gages on fabric.

Figure 4-22: Fabric strain gage installed and ready for embankment placement.

TABLE 4-1

TRADE NAME	MANUFACTURER	WEIGHT	MATERIAL
Typar	E. I. Dupont	4 oz/yd^2	Polypropylene & nylon
Mirafi	Celanese Fiber Marketing Co.	4 oz/yd^2	Polypropylene
Supac	Phillips Fiber Corp.	4 oz/yd^2	Polypropylene
Fibertex	Crown Zellerbach Corp.	9.45 oz/yd^2	Polypropylene
Fibertex	Crown Zellerbach Corp.	12.41 oz/yd^2	Polypropylene
Bidim	Monsanto Textile Co.	4 oz/yd^2	Polyester
Bidim	Monsanto Textile Co.	12 oz/yd^2	Polyester

Non-woven fabrics used in Quinault Trial-Use Installation.

CHAPTER 5: EARTH REINFORCEMENT

I. INTRODUCTION

The concept of earth reinforcement is the use of fabric to increase the overall strength of a soil fabric system. The primary function is earth strengthening.

Fabric has been used in the construction of retaining walls on the Siskiyou and Olympic National Forests (21, 22, and 23). This type of construction consists of horizontal layers of fabric placed in an earth fill with the edge of the fabric folded back around a berm and lapped over the next layer to form the wall face (Figures 5-1 and 5-5). At the face of the wall the fabric retains soil material from running out while in the interior of the fill, fabric tensile strength is developed through friction with the soil layers.

In addition to retaining walls, the fabric reinforcement concept has been used to transfer load from a fill to pile caps to prevent settlement of a bridge abutment backfill over very soft soils (Figure 5-2) (19).

Another case where earth reinforcement has been used is to support earth fills on soft soil (Figure 5-3). Where a single fabric layer is used lateral spreading of the underlying soil is prevented. Where multiple fabric layers are used a raft foundation is developed.

II. FABRIC WALL THEORY

The wall is designed using the Rankine approach as described by Bell (23). Lateral pressures are developed from 1) earth pressures

behind the wall, and 2) live loads on top of the wall.

A. Earth Pressure

Lateral earth pressure at any depth below the top of the wall (Figure 5-1a) is given by:

$$\sigma_{h_o} = K_o \gamma d \qquad \text{(Eq. 5-1)}$$

where: σ_{h_o} = lateral earth pressure acting on the wall.

K_o = at rest pressure coefficient.

γ = soil unit weight.

d = depth below the top of the wall.

A typical earth pressure distribution is shown in Figure 5-1b. Use of the at rest pressure coefficient, K_o , as recommended by Lee (25), is given by:

$$K_o = 1 - \sin \phi \qquad \text{(Eq. 5-2)}$$

where ϕ is the angle of internal friction of the soil.

The failure surface, AB in Figure 5-1a, slopes upward at an angle of $\theta = 45 + \phi/2$.

B. Live Load Pressure

Lateral pressures from live loads are calculated from the Boussinesq equations (24). For a point load acting on the surface of the backfill the equation is:

$$\sigma_{h\ell} = P x^2 z / R^5 \qquad \text{(Eq. 5-3)}$$

where P = vertical load.

X = horizontal distance from load to wall, perpendicular to the wall.

y = horizontal distance from load to wall, parallel to the wall.

z = vertical distance from load to point where stress is being calculated.

$R = \sqrt{x^2+y^2+z^2}$

A typical live load pressure distribution is shown on Figure 5-1b. Reference 24 and Figure 4 show how to develop a live load pressure distribution.

C. Fabric Tension

Tension in any fabric layer is equal to the lateral stress at the depth of the layer times the face area that the fabric must support. For a vertical fabric spacing of X, a unit width of fabric at depth d must support a force of $\sigma_h X$, where σ_h is the average total lateral pressure (composite of dead + live load) over the vertical interval X.

D. Pullout Resistance

A sufficient length of fabric must be embedded behind the failure plane to resist pullout. Thus, in Figure 5-1a, only the length, Le; of fabric behind the failure plan AB would be used to resist pullout. Pullout resistance can be calculated from:

$$P_A = 2 d \gamma \text{ TAN } 2/3\, \phi \text{ Le} \qquad \text{(Eq. 5-4)}$$

where P_A = pullout resistance.

d = depth of backfill below top of retaining wall.

γ = unit weight of backfill.

ϕ = angle of internal friction of backfill.

L_e = length of embedment behind the failure plane.

It can be seen from this expression that pullout resistance is the product of overburden pressure, γd , and the coefficient of friction between soil backfill and fabric which is assumed to to be $\tan 2/3\phi$. This resistance is in lbs./ft.^{2} which is multiplied by the surface area of $2 L_e$ for a unit width.

Where different soils are used above and below the fabric layer, the expression is modified to account for different coefficients of friction for each soil:

$$P_A = d\,\gamma\,(\tan 2/3\,\phi_1 + \tan 2/3\,\phi_2)\,L_e \qquad \text{(Eq. 5-5)}$$

III. DESIGN PROCEDURE

The recommended design procedure follows these steps:

A. Determine backfill properties ϕ and γ .

B. Develop lateral earth pressure diagram.

C. Using appropriate live loads (consider legal and oversize loads), develop a live load lateral pressure diagram.

D. Combine earth and live load pressure diagram into composite for design.

E. Determine vertical spacing of fabric layers.

F. Determine length of fabric required to develop pullout resistance.

G. Determine length of overlap for the folded portion of fabric at the face.

H. Check external wall stability.

Calculations for the fabric dimensions for overlap, embedment length and vertical spacing should include a safety factor of 1.5 to 1.75 depending on the confidence level in the strength parameters.

Fabric strengths used are the Oregon State University ring test strength which is approximately 67% of the strip, or 33% of the grab test for strengths for non-woven needle-punched fabrics.

Following is a more detailed description of each step:

A. Determine backfill properties $\emptyset$ and γ Only free draining granular materials should be considered for backfill. The friction angle, $\emptyset$, can be estimated conservatively by a soils engineer or determined with appropriate direct shear or triaxial tests.

   Unit weight, γ , can be determined in a moisture density test. Generally, 95% of AASHTO T-99 maximum density can be easily attained with granular materials. However, other densities can be specified so long as the $\emptyset$ used is consistant with that density. The wet unit weight should be used in lateral pressure calculations.

B. Develop the lateral earth pressure diagram. Using the backfill properties determined in A, calculate $K_o = 1 - \sin \emptyset$. Using the lateral earth pressure expression:

$$\sigma_{h_o} = K_o \gamma h \qquad \text{(Eq. 5-1)}$$

Calculate the triangular shaped pressure distribution curve for the height of retaining wall desired.

C. Develop the live load lateral pressure diagram.

First, it is necessary to determine the design load. One method which has been used is to design using legal loads and an appropriate safety factor, say 1.75, and then design for heavy loads, such as yarders, using a safety factor of 1.5.

Lateral pressure diagrams must be developed for each piece of equipment using Equation 5-3. P is the load from each wheel of the vehicle, thus the equation is solved for each wheel and the results added to obtain the lateral pressure. This pressure is calculated at 2-foot vertical intervals over the height of the retaining wall. Normally, from one to three locations along the wall are checked to determine the most critical. Figure 5-4 shows an example calculation.

D. Develop composite pressure diagram. The earth pressure and live load pressure diagrams are combined to develop the composite diagram used for design as shown in Figure 5-1b.

E. Determine vertical spacing of the fabric layer.

Fabric strength, S, is set equal to the lateral force calculated from $\sigma_h X$, where σ_h is the lateral pressure at the middle of the layer. Thus, knowing the fabric strength (OSU ring strength), and value of σ_h , the fabric vertical spacing, X, can be calculated. The fabric strength should be divided by the appropriate safety factor as previously discussed. The

equation for fabric spacing is:

$$X = \frac{S}{(F.S.)\sigma_h} \qquad \text{(Eq. 5-6)}$$

F. Determine length of fabric required to develop pullout resistance.

The formula for pullout resistance, $P_A = 2d\gamma \mathrm{TAN}\, 2/3\phi L_e$, can be used to solve for P_A, the pullout resistance which can be developed at a given depth-fabric length combination or to solve for d, the depth required to develop P_A. The usual case for walls is to set P_A equal to the fabric strength and solve for Le, the length of fabric required. Thus, the expression would be:

$$L_e = \frac{P_A}{(F.S.)(2d\gamma \mathrm{TAN}\, 2/3\,\phi)} \qquad \text{(Eq. 5-7)}$$

where P_A = O.S.U. ring strength.

F.S. = Safety factor of 1.5 to 1.75

A minimum value of Le = 3 feet should be used.

G. Determine length of fabric overlap for the folded portion of fabric at the face.

The overlap, L_o, must be long enough to transfer the stress from the lower section to the longer layer above.

Fabric tension is given by:

$$f = d_F \gamma \mathrm{TAN}\, 2/3\,\phi L_o \qquad \text{(Eq. 5-8)}$$

Friction resistance is:

where d_F = depth to overlap.

The factor of safety can be expressed as:

$$F.S. = \frac{f}{T} = \frac{d_F \gamma \, TAN \, 2/3 \, \phi \, L_o}{\sigma_h \left(\frac{X}{2}\right)} \qquad (Eq. 5\text{-}9)$$

This can be solved for the length of overlap required:

$$L_o = \frac{\sigma_h X \, (F.S.)}{2 \, d_F \, \gamma \, TAN \, 2/3 \, \phi} \qquad (Eq. 5\text{-}10)$$

A minimum value of L_o = 3 feet should be used to insure adequate contact between layers.

H. Check external wall stability.

Once the internal stability of the structure is satisfied, the external stability against overturning, sliding and foundation bearing capacity should be checked.

Overturning loads are developed from the lateral pressure diagram for the back of the wall. This may be different from the lateral pressure diagram used in checking internal stability, particularly due to placement of live loads. Overturning is checked by summing moments of external forces about the bottom at the face of the wall.

Sliding along the base is checked by summing external horizontal forces. Bearing capacity is checked using foundation bearing capacity factors (8, 12, 20).

Theoretically, the fabric layers at the base could be shorter than at the top. However, because of external stability considerations, particularly sliding and bearing capacity, all fabric layers are normally of uniform width.

I. Other Considerations

Fabric materials in the wall are subject to degradation from ultra-violet rays. Therefore, the wall face must be coated to provide protection. A 0.25 gal./yd.^{2} application of CSS-1 emulsified asphalt has provided adequate protection for the Shelton test wall. Gunnite, used on the Siskiyou wall, provides the additional benefit of protecting the cloth face from vandalism.

Fabrics are manufactured in widths up to 17½ feet. Where greater widths are required, the fabric should be turned so that one piece is used. No longitudinal splices should be made.

At this time earth reinforcement projects should be constructed under the trial use procedure to enable gathering of data on design and construction procedures, and monitoring of performance. This data base will provide information for preparing design procedures and standards for future general use.

Cost of the Olympic wall was approximately $11.50 per square foot, including supervision and overhead, for 2,100 square feet of wall. However, this cost included equipment time during the instrumentation installation. Actual equipment cost would be somewhat lower. Items to consider in estimating are excavation for the wall, fabric material and installation, backfill including haul and layer placement and wall face protection.

IV. TEST WALLS

Two fabric walls have been constructed in Region 6. The first was constructed on the Siskiyou National Forest in December, 1974 and the second on the Olympic National Forest in May, 1975. The Olympic wall was instrumented to measure fabric stress and monitor movements in the wall and environmental effects on the fabric.

OLYMPIC WALL

The retaining wall site is located in steep terrain with 1-1/4:1 (80%) side slopes below the road and a 100 - foot rock cut adjacent to the site. These conditions necessitated use of a retaining wall to gain additional road width. The site required a wall 166 feet in length and 18.5 feet high at its highest point.

Locally available material was used for backfill. This consisted of an open graded 3-inch minus crushed rock with the properties shown on Figure 5-6. Values of $\emptyset = 40^{o}$ and maximum dry density of 125 lb./ft.^{3} were used for design. Additionally, it was assumed that friction between fabric and soil was 2/3 $\emptyset$ or 26.7^{o} and fabric to fabric friction was 20^{o}.

Fabrics used in the wall were a non-woven Polypropylene (Fibertex), manufactured by Crown Zellerbach, and a non-woven Polyester (Bidim) manufactured by Monsanto. Fabric strength properties are shown in Table 5-1. The fabric dimensions were calculated using a factor of safety of 1.75, and a 48^{K} dual tandem wheel live load. These calculations required minimum values of overlap of 0.42 foot and embedment length behind the failure plane of 0.82 foot. Because of uncertainties in

construction, these lengths were increased to 3.5 and 3 feet respectively. The combined overlap, embedment, curve length of the face, and length from face to failure plane required a total fabric width of 15.75 feet. This was within the fabric's manufactured width of 16.4 and 17.5 feet.

A. Construction

Construction was performed jointly by Simpson Timber Company which provided the backfill material and heavy equipment, and the Forest Service which provided the fabric, instrumentation and labor. Construction time involved approximately 2-1/2 weeks. Construction was slowed due to installation of the instrumentation. Without instrumentation, we estimate construction should take no longer than about 1-1/2 weeks.

Construction followed this sequence: First, the excavation was made and the foundation leveled using a 4-yard, track loader. Next, the temporary form system was set in place and the first layer of fabric rolled out. Thirdly, a 2-foot berm of compacted backfill was placed at the face and the fabric folded over the berm. Finally, the remaining backfill was placed, leveled with a JD 450 dozer, and compacted with at least two coverages of a rubber-tired loader. This process was repeated for each layer until the final height was reached. Figures 5-7 through 11 show the construction sequence.

The temporary forming system shown in Figures 5-12 and 13 consisted of a steel strap with a pipe upright. These were spaced at approximately 4-foot intervals on the previously constructed fabric layer. Where 12-inch layers were used, a 2"x12" plank was placed against the pipe upright. A 2"x4" was placed on top of this to attain the required uncompacted height. Where 9-inch layers were placed, only the 2"x12" was required. The next fabric layer was draped over the plank and the fill placed against it. After folding the fabric back, leveling and compacting the fill, the form was removed and repositioned for placement of the next layer. Total cost of constructing the 2,122 square foot wall, including supervision and overhead, was $24,525, or $11.56 per square foot.

B. Instrumentation

Several types of instrumentation were installed to monitor movements of the wall. These included vertical and horizontal inclinometers, inductance type settlement meter and vertical and horizontal survey monuments. The three vertical inclinometers were destroyed during construction before any readings could be taken.

Twenty-six horizontal inclinometers were installed at the locations shown in Figure 5-5. Four sets of readings have been taken between June 1975 and January 1977. With the exception of two tubes in the top of the wall, the data shows vertical movements on the order of 0.1 foot or less with most movements less than

0.05 foot. In the D row (Figure 5-14), the top tube showed movement of 1.5 foot while the next lower tube moved 0.75 foot. This movement appears to have taken place during construction after the initial readings were taken.

One hundred sixty-six slip rings were installed over the horizontal inclinometer tubes as shown on Figure 5-5. These slide with the backfill material and provide information on horizontal movements. The four sets of readings show no horizontal movement has taken place with the exception of the slip ring nearest the wall face in each row. The horizontal measurement from the end of the tube to the first slip ring has shortened from 0-0.17 of a foot since December 1975. The orientation of this movement is shown in Figure 14.

A transit line was set up to measure horizontal movement of the end of the horizontal inclinometer tubes. Data here shows horizontal movement of the end of the tube of 0.02 to 0.17 foot, as shown in Figure 14.

Elevations which have been taken on the ends of the inclinometer tubes, indicate no change in elevation has occurred.

C. Conclusions

The data indicates that no vertical movements are taking place at the face of the wall and only slight vertical movements within the wall. The horizontal data shows some movement in the outer

three feet of wall. This horizontal movement may be due to downhill creep of the foundation soil or a redistribution of the backfill material due to differential compaction near the face. All movements have been lower than expected and occurred between the sixth and eighteenth month after construction. Large movements had been anticipated due to the high strain properties of the fabric.

The wall appears to be performing satisfactorially at this time. The asphalt coating appears to have provided adequate protection from ultra-violet deterioration. However, portions of the asphalt coating appear to have been absorbed into the fibers or have washed off, therefore, a second application of CSS-1 emulsion at 0.25 gallon per square yard or less is planned for the summer of 1977.

One unexpected problem did occur when vandals slashed a portion of the face soon after construction. However, this was repaired by stitching the fabric back together and the patch is still functioning. Repairs of this type could also be made by sewing a patch over the cut area. The wall constructed on the Siskiyou National Forest was faced with gunnite. This seems to be more permanent and is less susceptible to vandalism.

The temporary forming system worked well; however, the following changes are suggested to improve the system for future use:

1. The strap should be about 24 inches long in order to provide adequate length for a temporary anchorage.

2. The 2"x12" plank is heavier than necessary. Three-quarter-inch plywood will be heavy enough for the temporary form. Holes should be cut near the top of the boards to provide hand holds for easier handling.

3. Wood wedges should be used to support and align the straps at the face of the wall.

4. Form support pipes should be 2" shorter than the top of the form to minimize fabric tearing.

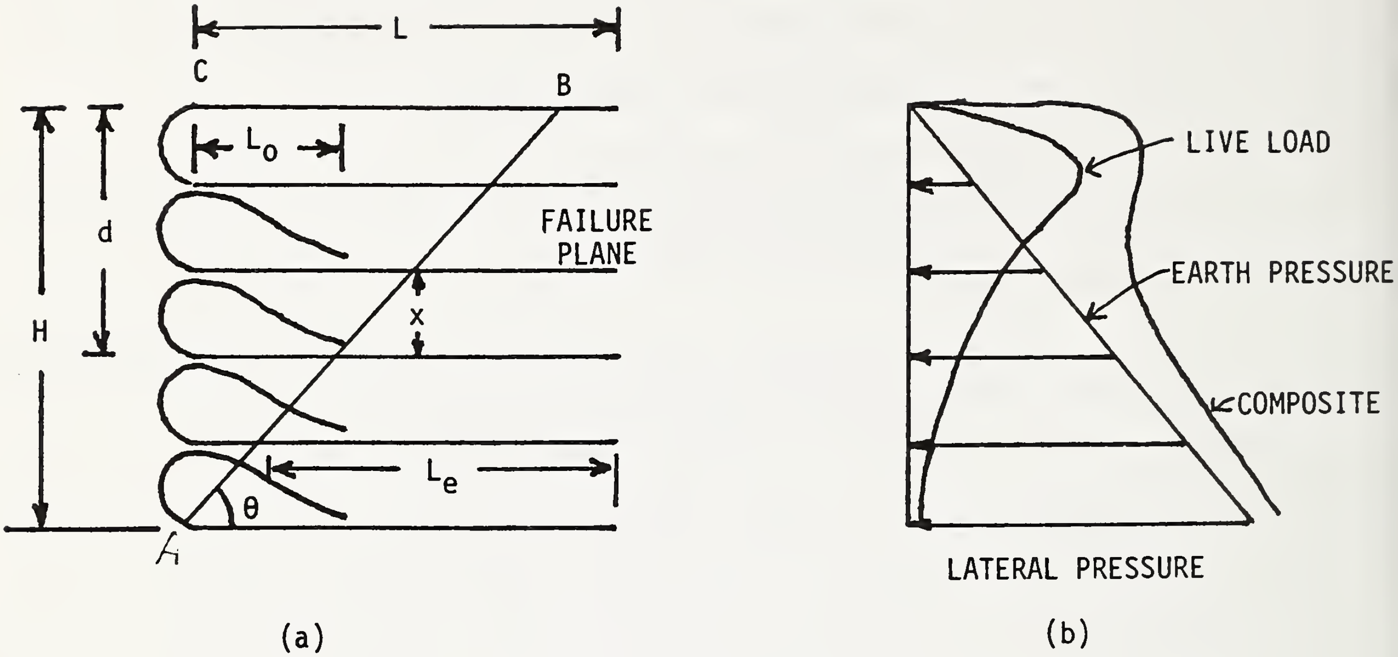


FIGURE 5-1. Sketch of section through fabric retained earth wall and assumed earth pressure distribution.

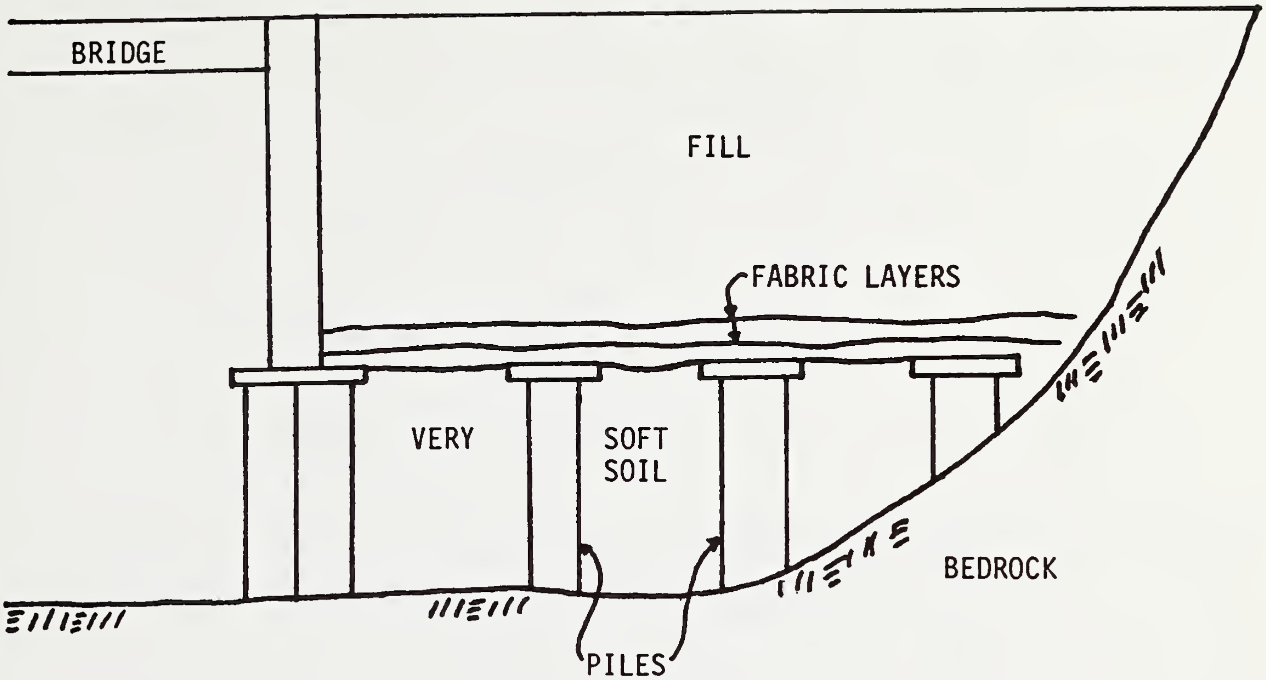


FIGURE 5-2. Fabric Reinforced Bridge Abutment.

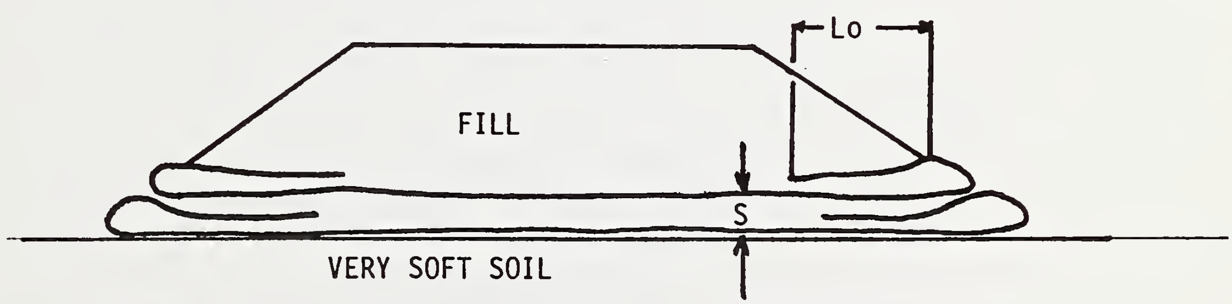
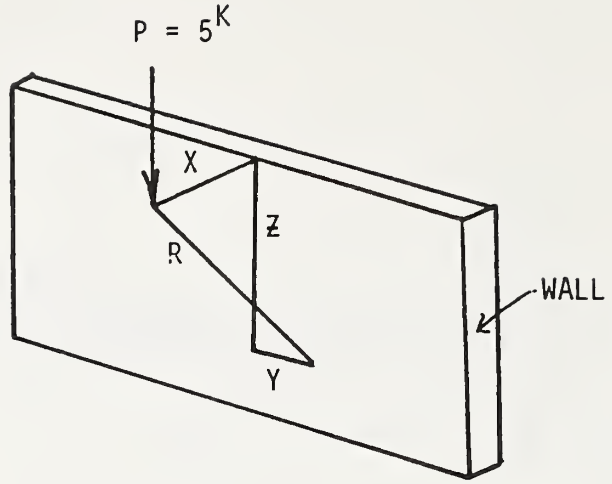
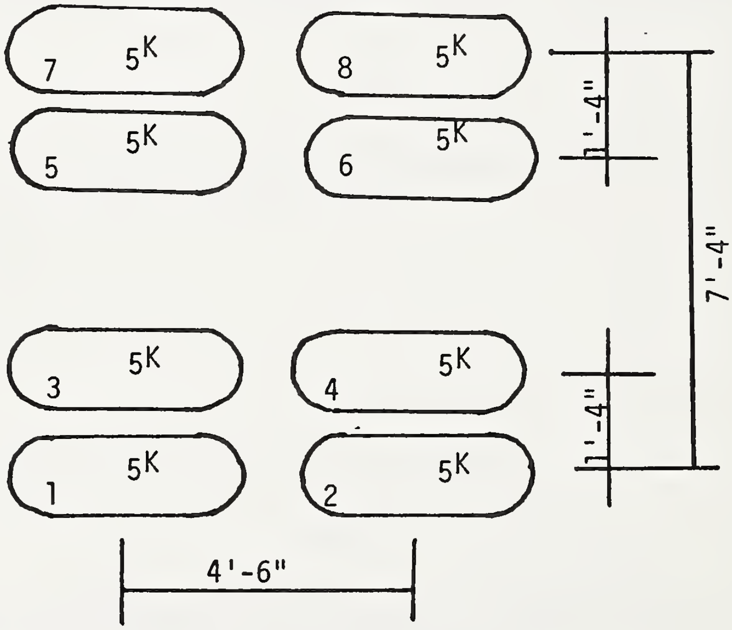


FIGURE 5-3. Fabric Reinforcement of a Fill Over Soft Soil.



Use of $\sigma_h = P\frac{X^2 Z}{R^5}$ for calculating lateral pressure from a point load.



40^k Dual Tandem Axle

FIGURE 5-4(a)

Stresses from Outside Tire of Outside Dual (1 & 2)

X	Y	Z	σ_{hi} (Lb/Ft^2)	X	Y	Z	σ_{hi} (Lb/Ft^2)
2.5	0	1	221	2.5	4.5	1	59
		2	186			2	68
		3	103			3	50
		4	54			4	32
		6	16			6	12
		10	3			10	2

Stresses from Inside Wheel of Outside Dual (3 & 4)

X	Y	Z	σ_{hi}	X	Y	Z	σ_{hi}
3.83	0	1	75	3.83	4.5	1	9
		2	97			2	16
		3	81			3	17
		4	56			4	16
		6	24			6	10
		10	5			10	5

Total Stresses from All Wheels:

Wheel	Z = 1	2	3	4	6	10
1	221	186	103	54	16	3
2	59	68	50	32	12	2
3	75	97	81	56	24	5
4	9	16	17	16	10	5
Total Stress	364	367	251	158	62	15

FIGURE 5-4(b)

Figure 5-5

CROSS-SECTION OF INSTRUMENTED FABRIC WALL

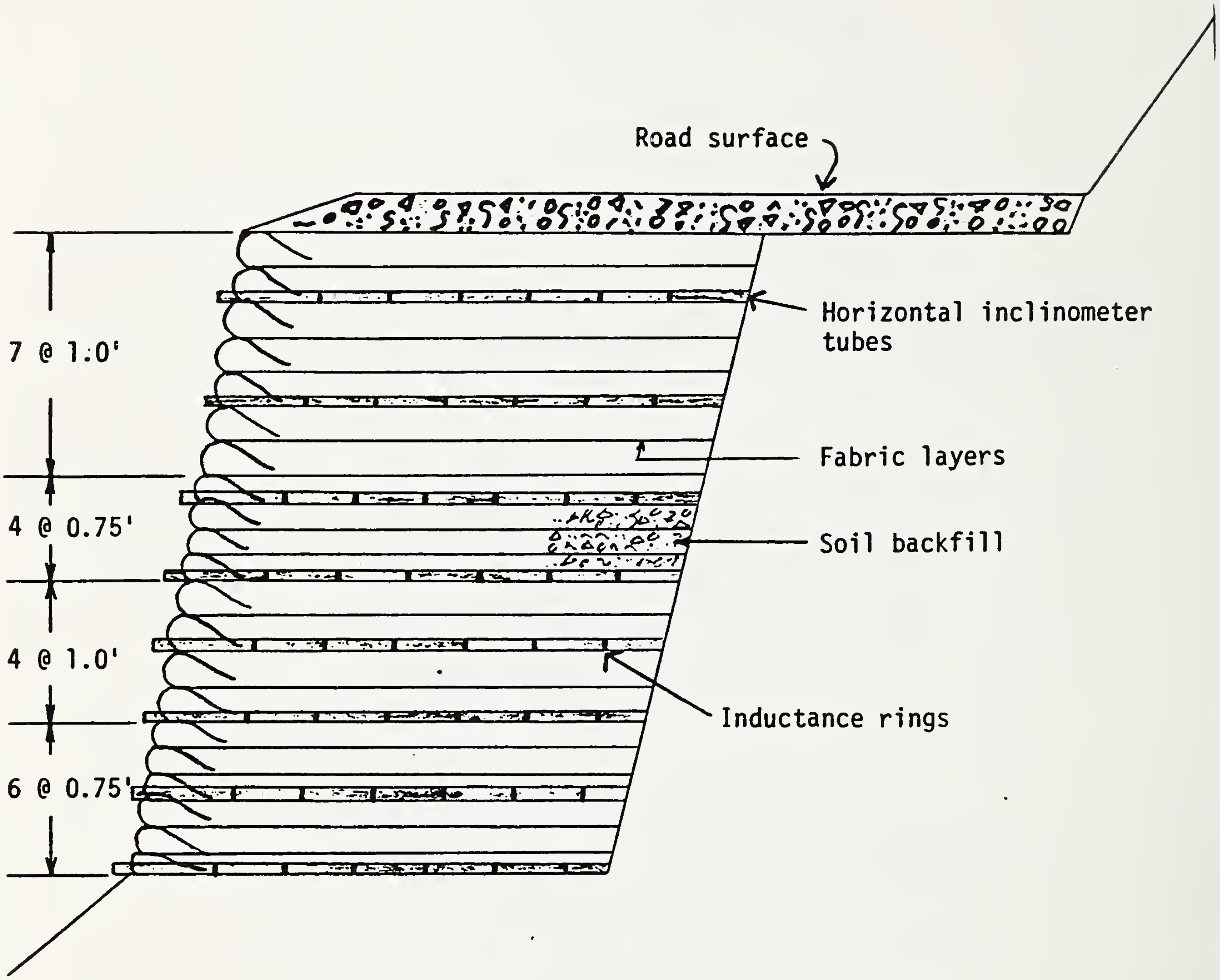


Figure 5-6

BACKFILL MATERIAL PROPERTIES - OLYMPIC WALL

ABRASION, % LOSS (AASHTO T 96 GRADING A) = 38
OREGON AIR DEGRADATION
P#20 = 47.9
H = 8.5

DURABILITY (AASHTO T 210): D_c = 61, D_f = 46

SPECIFIC GRAVITY OF SOILS (AASHTO T 100):
AT 20° C = 2.933

MAXIMUM DRY DENSITY = 113.8 LBS/FT^3
(EQUIPMENT USED TO OBTAIN THIS DENSITY:
HUMPHRIES GRANULAR COMPACTION DEVICE)

SPECIFIC GRAVITY & ABSORPTION OF AGG. (AASHTO T 85)
SSD = 2.781
DRY = 2.671
APP. = 3.001
ABS. = 4.110

AASHTO T 11/T 27 SIEVE OR SCREEN	% PASSING
75.0 (3")	100.0
50.0 (2")	83.6
37.5 (1 1/2")	55.7
25.0 (1")	30.9
19.0 (3/4")	20.2
12.5 (1/2")	12.2
9.50 (3/8")	10.5
4.75 (# 4)	8.6
2.00 (# 10)	7.7
0.42 (# 40)	5.8
0.075 (# 200)	2.9

UNIT WEIGHT, LOOSE = 1,386 kg/m^3 (86.5 pcf)
UNIT WEIGHT, RODDED = 1,593 kg/m^3 (99.4 pcf)

Note: above unit weight tests were performed on aggregate passing a 1 1/2 inch (37.5mm) sieve. Tests were run according to AASHTO T19 except the aggregate was tested air dried then corrected to dry unit weight.

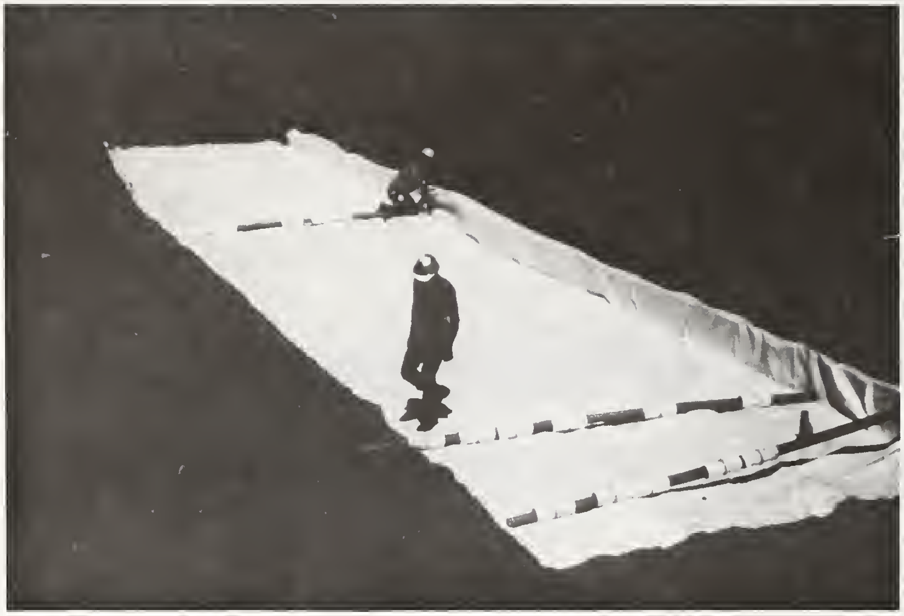


Figure 5-7. Fabric layer and temporary form in place for backfilling. Horizontal inclinometers and slip rings are being installed.

Figure 5-8. Backfill in place.

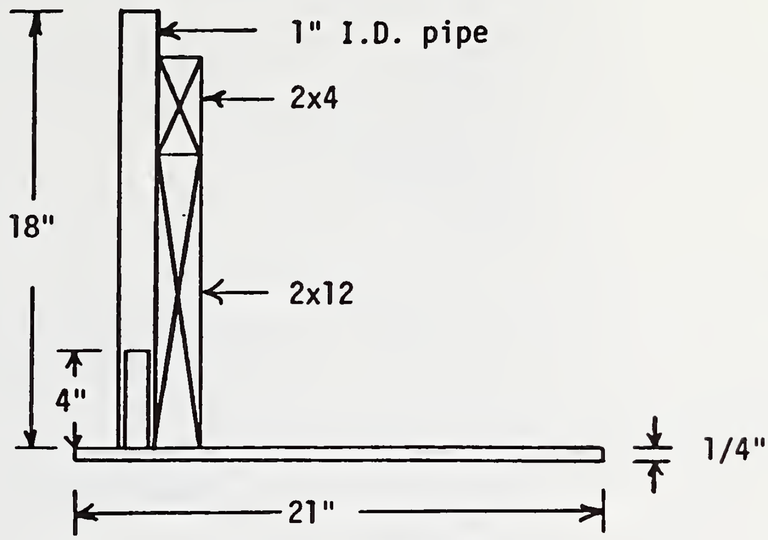
Figure 5-9. Wall partially constructed showing overlap draped temporarily over the form. Note inclinometer tubes protruding from wall face.

Figure 5-10. Overlap being made prior to placing next layer of fabric and backfill.

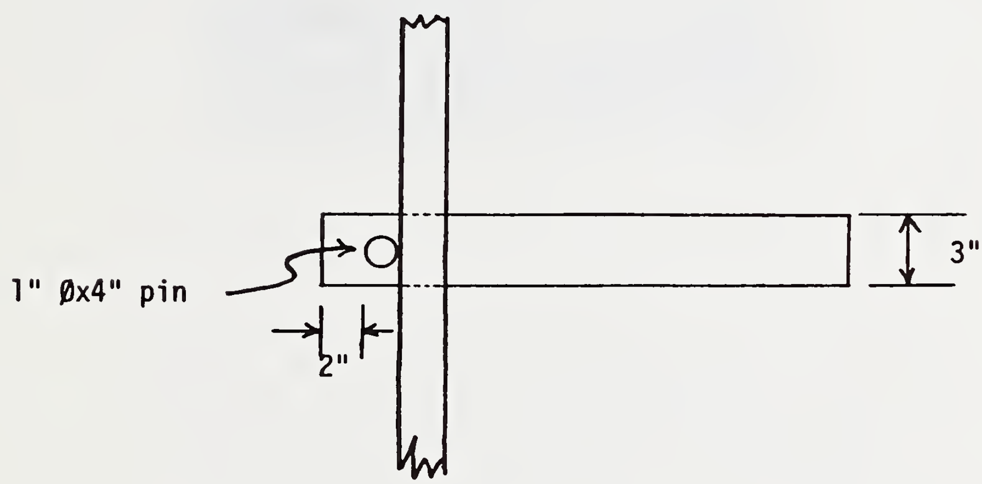
Figure 5-11: Backfill being placed as wall nears completion.

Figure 5-12

TEMPORARY FORM SYSTEM

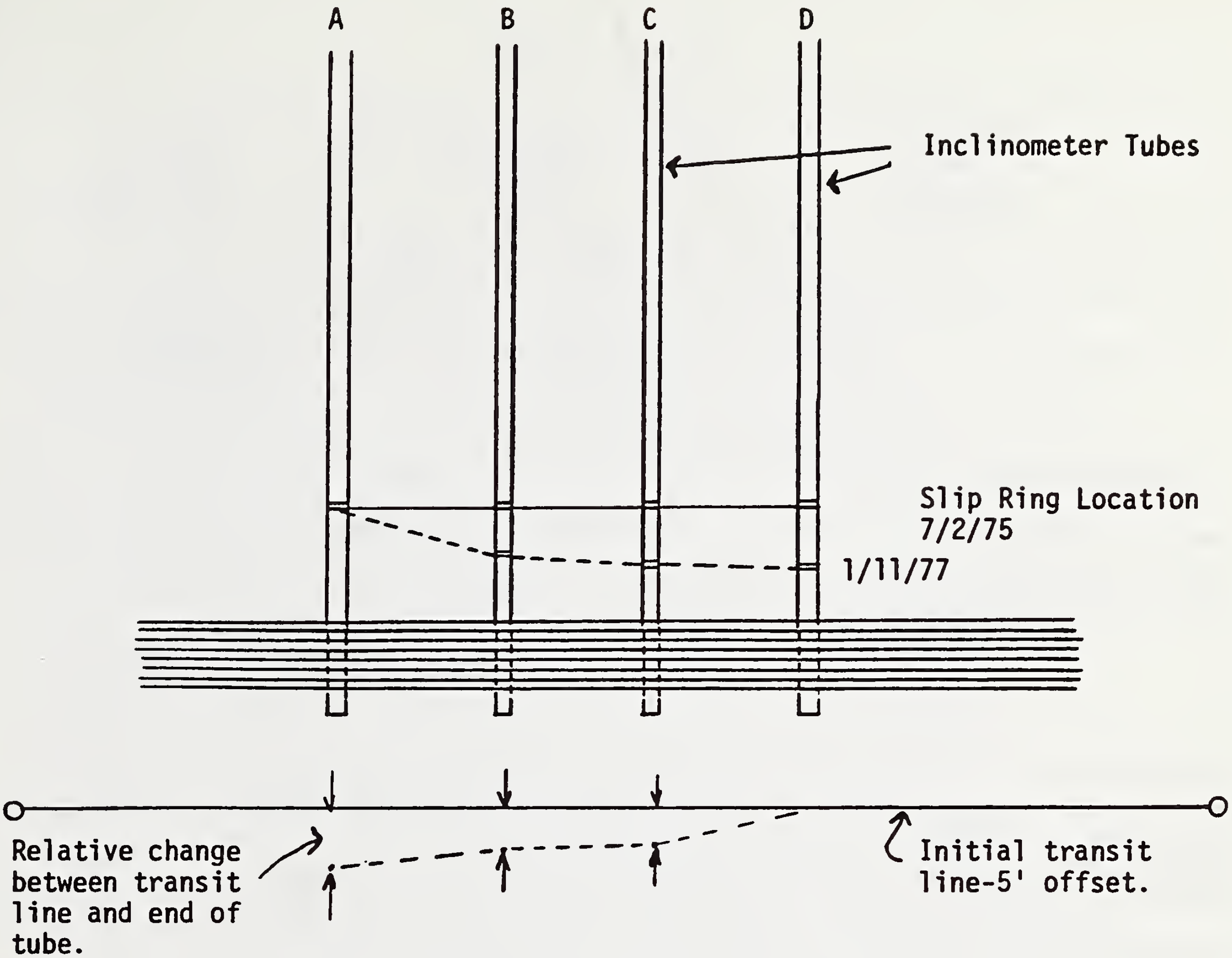


ELEVATION

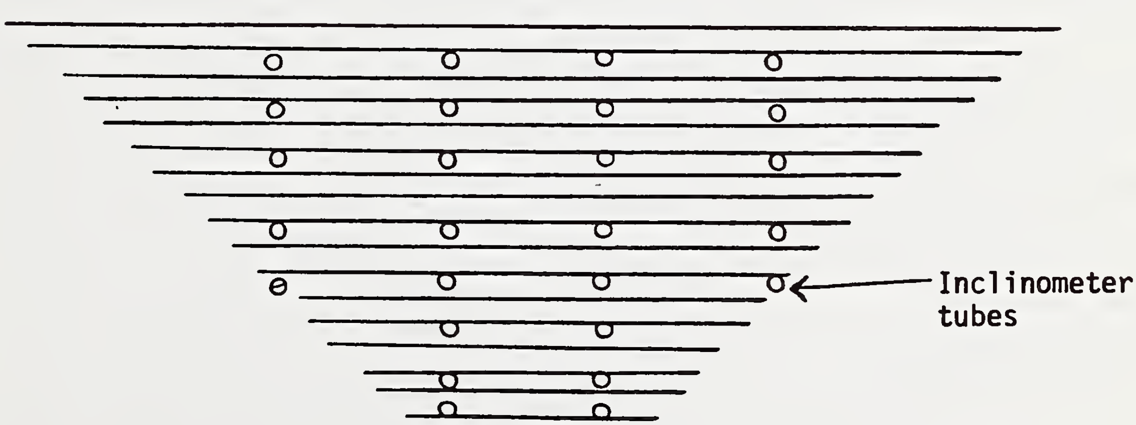


PLAN

Figure 5-13: Note temporary form system in place.



PLAN



ELEVATION

FIGURE 5-14

FABRIC PROPERTIES

MANUFACTURER OR SUPPLIER	MONSANTO TEXTILES COMPANY		CROWN ZELLERBACH CORPORATION	
Trade Name	Bidim C-28	Bidim C-38	Fibertex	
Construction	Non-Woven, spunbonded Polyester, needle punched		Non-woven, spunbonded Polypropolene, needle punched	
Thickness, mils	95	114	190	250
Weight, oz/yd^2 ($^{gm}/_{m^2}$)	5.9 (200)	12.4 (420)	12.4 (420)	17.7 (600)
Equivalent opening size (EOS) U. S. standard sieve	80	80		
% Open Area				
Strip test, 1" wide ASTM D-1682 Warp/Fill (lb/in) Elongation, %			100	150
Grab Test ASTM D-1682 Warp/Fill (lb/in) Elongation, %	213	290	150	250
Oregon State U. Ring test, lb/in (Design values - based on limited testing in 1975) % Elongation	60	108	65	98
Burst, lb ASTM D751	397	503		
Seam Strength				
Abrasion resistance, lbs. after 1000 cycles				
Width, ft.	13.8-17.4	13.8-17.4	17.3	17.3
Length, ft.	990	990	140	100

TABLE 5-1

CHAPTER 6: EROSION CONTROL

Erosion control is the use of fabrics to: 1) prevent movement of surface soils; 2) remove soil from water on the earth's surface, and 3) promote soil protecting growth. The primary function of the fabric is to: prevent surface soil movement. Fabrics are discussed in this chapter to demonstrate some of the potential uses of fabrics for erosion and sediment control. Properly utilized, fabrics can be a very effective and economical alternative to more conventional methods of erosion control. Conventional techniques for erosion and sediment control are treated adequately in other reports (18).

Figures 6-1 and 6-2 illustrate the use of fabrics as silt barriers. To be effective: a) all silt carrying surface water must be directed through the fabric, b) the fabric must have openings small enough to trap most of the soil but porous enough to pass the water with only a slight buildup of water pressure, and c) the fence structure must be adequate to support the pressure of the silt and water.

Figure 6-3 illustrates the use of fabric ditch liners below culvert outlets to prevent erosion of soils until vegetation can be established. A porous fabric is used to prevent sheet and gully erosion and permit the water to soak into the soil. The fabric is temporary since it degrades in sunlight. As the fabric degrades, its erosion prevention function will be replaced by plant growth. This technique should only be attempted on culverts having low volume intermittent flow in non-critical areas. Water from culverts with heavy flows or located in critical areas should be handled more positively by use of conduits or armored channels.

Several installations of fabrics for protection of culvert outlet areas were installed on the Umpqua N. F. in 1973. The installations were working adequately when last checked one year after installation.

Probably the most promising area for fabrics in erosion control is their use as a combination mulch and erosion preventor. Materials manufactured for this purpose are generally a light weight woven on non-woven fabric used to hold seed and mulch in place or fabric woven with paper or wood to prevent erosion and act as a mulch (Figure 6-4). Fabrics used for erosion control and mulching currently cost $0.45 to $0.60 per square yard for the material, and $0.80 to $1.00 per square yard installed, depending on the size and complexity of the project. Although the costs, when compared to other commonly used mulch systems may appear high, the fabrics can be more positive and cost effective on steep erodible slopes, by minimizing erosion and eliminating the need for replanting. Fabrics can be used for scour protection beneath revetments and around bridge foundations as illustrated in Figures 6-5 and 6-6. The fabric is held in place by rock rip-rap. Both the fabric and rip-rap allow water passage; however, the fabric keeps soil particles from being remove by scour action.

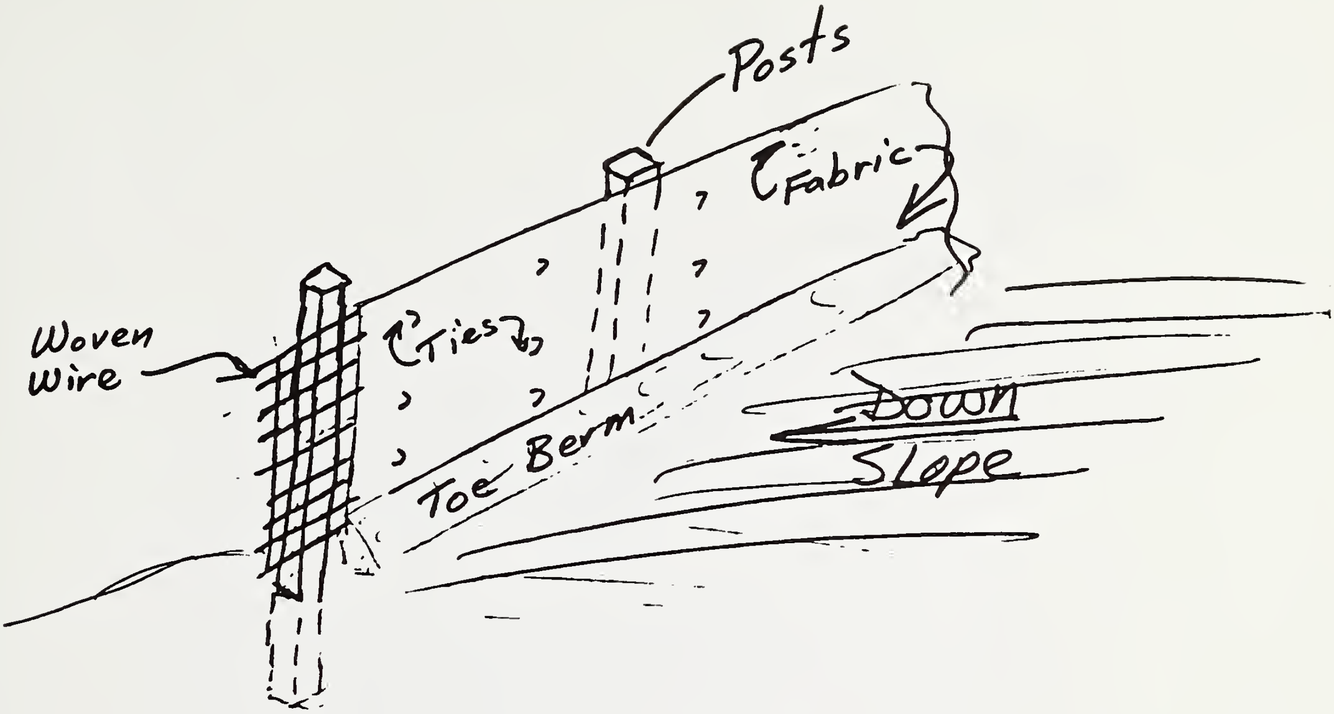


Figure 6-1 Silt Fence

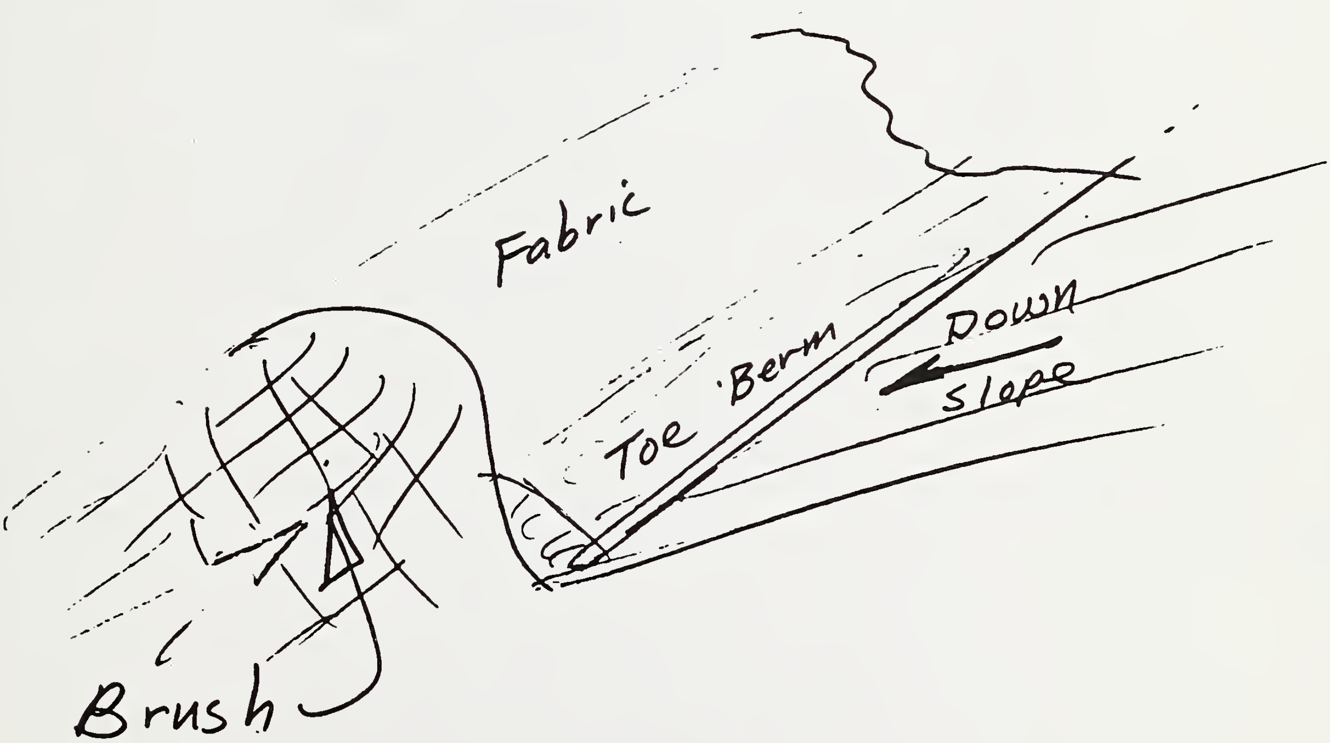


Figure 6-2 Silt barrier (Brush)

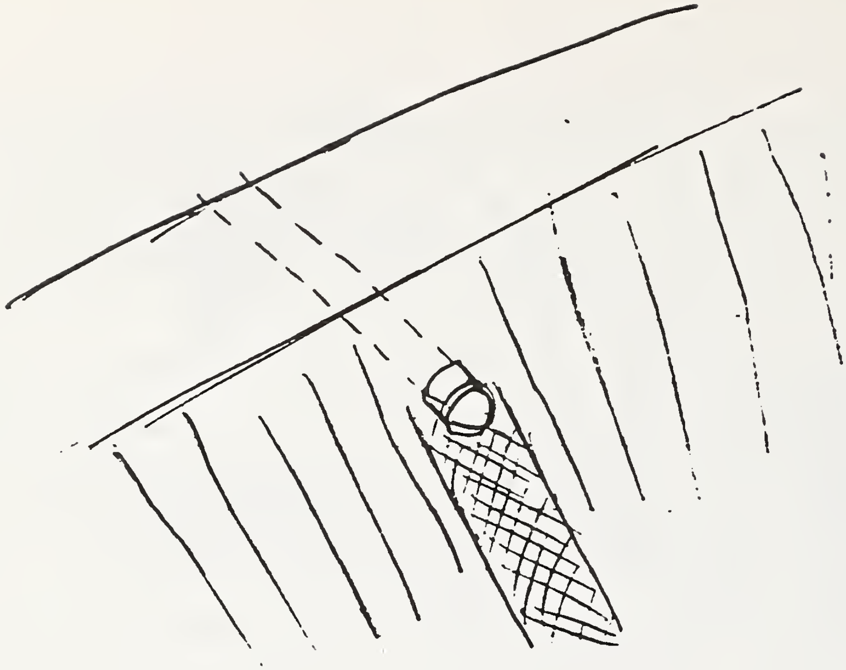


Figure 6-3. Fabric Culvert Apron

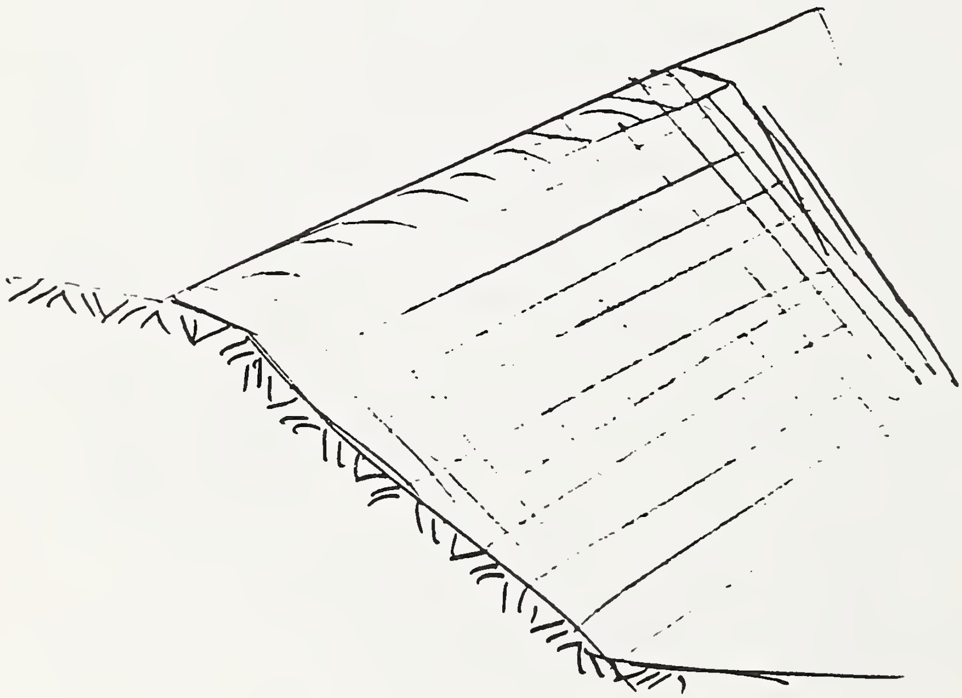


Figure 6-4. Fabric Slope Protection
(Erosion Prevention and Mulch).

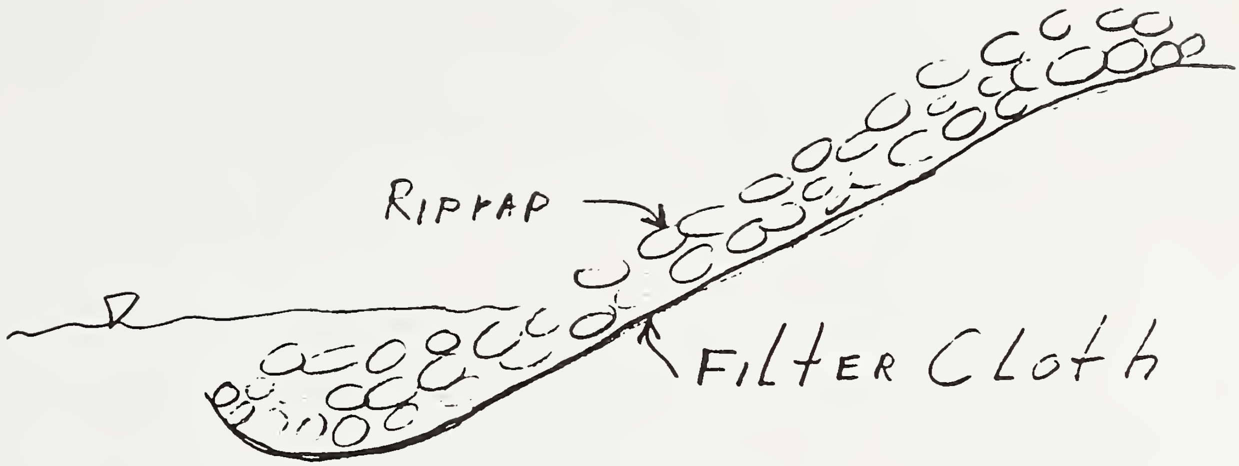


Figure 6-5 - Pavement

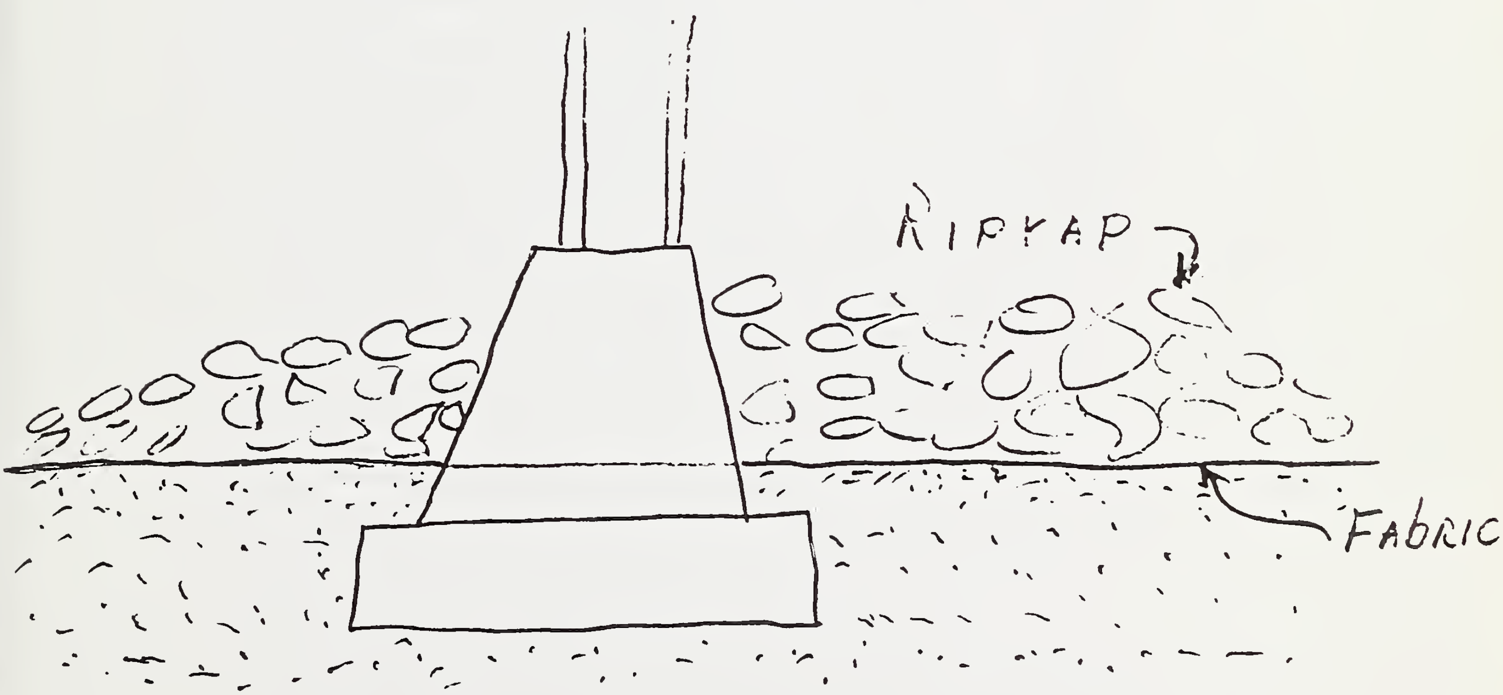


Figure 6-6 - Scour Protection

CHAPTER 7: PHYSICAL PROPERTIES

Table 7-1 contains a summary of some physical properties of 28 styles and weights of fabrics from 11 suppliers. Names and addresses of the suppliers are shown in Table 8-2.

With the exception of the OSU Ring Test, physical properties in Table 7-1 were taken from brochures or supplied by the manufacturers and are not covered by U.S.F.S. testing specifications and procedures. Values reported may be minimum, average, or maximum values for a series of tests on a fabric. OSU Ring Tests were performed in our testing laboratory and are the average of five tests.

Tables 7-2, 7-3 and 7-4 summarize the results of some recent fabrics tension tests performed in our Regional testing laboratory. Unless noted otherwise, these tests were performed on four-inch wide cut strips at a testing rate of 12 inches/minute. The four-inch width was selected to minimize fabric edge effects. A series of tests on fabric strips 1 inch to 12 inches wide revealed that for most non-woven fabrics, the strength per inch of width decreased considerably for widths smaller than four inches and increased a minor amount for widths greater than four inches.

Average strength, elongation, and standard deviation are shown for five or more test specimens. Less than five specimens were tested (typically one or two) where no standard deviation is shown.

The OSU Ring Test was developed by Oregon State University (23) to obtain strength and elongation values for fabrics in plane strain. The earliest tests performed using the OSU Ring Test at a rate of 0.08 inches/minute

yielded values equal to about 75% and 33% of the strip test and grab test values, respecitvely. These OSU Ring Test values were used in design of the fabric walls (21, 22, 23). More recently, the average of five samples tested at 12 inches/minute resulted in OSU Ring values equal to 80 to 170% of the strip values and 30 to 120% of the grab values.

Strength and Elongation: Although most tests were run according to ASTM Standards,where an average of at least five tests is reported, the standards permit the tester to vary the fabric and jaw width for testing. Since most manufacturers do not report the width of the fabric and jaws or the variation in test results, the strength reported in TAble 7-1 can only be used as indicators, not as absolute values.

The purpose for listing numerical values for several strength tests on a fabric is that the strip, grab, burst and abrasion tests are common to the textile industries. Their validity for fabrics used in construction that are buried in the soil and restrained in several directions from moving has not been established. The listed values give an indication of the relative strength of the individual fabrics.

Tables 7-2 and 7-3 indicate a significant difference in the stress-strain properties in the warp and fill directions for the non-woven fabrics tested. The results also indicate a strength variation of as much as 10 to 15 pounds per inch and an elongation variation of 10 to 25% elongation can be expected in a series of tests. These tests confirmed our visual observation that many of the lighter weight non-woven fabrics showed a variation in fiber density when viewed against a lighted background.

It is important to point out the subtle difference between the grab and strip test, particularly for the non-woven fabric. Grab test values (fabric is wider than the jaws) are considerably higher than the strip test values (fabric is the same width as the jaws) because many of the fibers held in the grips will be physically cut during the process of forming the strip for the test. The grab test, on the other hand, permits the majority of the fibers held in one grip to be held in the second grip and are supported by the adjacent fabric. Grab and strip test results for woven fabrics should be nearly identical.

The high elongation properties measured when testing the non-woven fabrics in the strip and grab tests appear to be misleading when applied to fabrics confined in a soil mass. In the grab and strip test, the individual fibers are restrained from moving only at the grips. Much of the elongation comes from the process of aligning the fibers prior to breaking. The woven fabrics made of essentially the same materials as a non-woven fabric exhibit 10 to 30 percent of the elongation at failure shown by the non-wovens. This is probably due to the fact that the fibers are already aligned between grips when the testing begins.

The stress-strain relationship for non-woven fabrics used in soil and pavement applications appears to approach that of the individual fibers and that of woven fabrics made from the same materials. The fibers in fabrics underground are gripped tightly by the soil and fabric to prevent large amounts of fiber realignment during loading. This appears to be the case in both the Shelton fabric wall test and the Quinault subgrade restraint test road where the strains were much less than predicted by the calculated stress (17, 21, 22).

Field Performance: Fabrics described in this chapter will all break down when exposed to sunlight (ultraviolet) for a period of time. The length of time required to break down the fabric depends on the amount and type of stabilizers used in the manufacutring process. Untreated polypropylene and polyester samples left exposed in the field completely disintegrated within 18 months (21) (Table 7-4). The polypropylene had noticeable deterioration within two weeks of initial exposure. The fabrics are resistant to most soil and water conditions when protected from sunlight (2, 3, 9).

The higher strain fabrics may resist tearing and punching more than the lower strain fabrics during installation due to their ability to yield and conform to surface irregularities (21, 22). This is particularly noticeable in the needle-punched non-woven fabrics where the fibers are not tightly gripped in the unconfined fabric. Recently, one builder of logging roads switched from a 4 oz/yd^2 needle-punched fabric to a 4 oz/yd^2 heat-bonded because the needle-punched fabric was "too soft" and tended to bulge during rock placement. A stiff, low-pressure polyethylene net was successfully used in Japan to restrain soft soils (34).

It appears from our work with fabrics that the physical properties which control the performance of a fabric under field conditions have not been established. The most important fabric property for subgrade restraint is its ability to be installed undamaged. For filtration, the most important property is to remove water without plugging or piping of the soil. For separation, the most important property is the ability of the fabric to prevent mixing of two dissimilar materials. For earth reinforcement a predictable long term, high strength is required. For waterproofing, the fabric must have capacity to contain waterproofing material (asphalt).

Extensive testing needs to be performed on all of these fabrics under one set of test conditions to establish their relative physical properties. These physical properties need to be compared to field performance to establish suitable design criteria and specifications. Until this work is performed, considerable caution and judgment will be required in using fabrics for low volume road construction.

Table 7-1 - Physical Properties

MANUFACTURER OR SUPPLIER	CELANESE FIBERS MARKETING COMPANY	DU PONT TEXTILE FIBERS DEPARTMENT	CROWN ZELLERBACH CORPORATION		
Trade Name	Mirafi 140	Typar	Fibertex	Fibertex	Fibertex
Construction	Nonwoven Continuous Filament	Nonwoven Spunbonded Polypropo-lene	Nonwoven, Spunbonded Polypropolene, Needle Punched		
Thickness, mils	30	15	125	190	250
Weight, oz/yd^2 ($^{gm}/_{m^2}$)	4 (140)	4 (140)	9.4 (320)	12.4 (420)	17.7 (600)
Equivalent opening size (EOS) U.S. Standard Sieve	100				
%Open Area					
Strip Test, 1" Wide ASTM D-1682 Warp/Fill (lb/in) Elongation, %	25		75	100	150
Grab Test ASTM D-1682 Warp/Fill (lb/in) Elongation, %	120 130	160/160 60/65	125	150	250
Oregon State U. Ring Test, lb/in Wet/Dry @ 12 in./min. % Elongation Wet/Dry	35.0/50.0 115.0/75.0	60.0/60.0 90.0/80.0	90.0/100.0 200.0/150.0	170.0/170.0 375.0/330.0	
Burst, lb ASTM D751	120	190			
Seam Strength					
Abrasion Resistance lbs. after 1000 cycles					
Width, Ft.	14.75	12.5 & 15.5	17.3	17.3	17.3
Length, Ft.	328	300,900,3000	180	140	100

MANUFACTURER OR SUPPLIER	ERCO SYSTEMS, INC.		PHILIPS PETROLEUM COMPANY		MENARDI-SOUTHERN DIVISION OF U.S. FILTER CORP.
Trade Name	Nicolon 66411	Nicolon 66301	Petromat	Supac	Monofilter
Construction	Woven Polypropolene	Woven Polypropolene	Nonwoven Polypropolene	Nonwoven Polypropolene	Woven Polypropolene
Thickness, mils				40	20
Weight, oz/yd^2 ($^{gm}/_{m^2}$)			4.2 (140)	4.1 (140)	7 (245)
Equivalent opening Size (EOS) U. S. Standard Sieve	30				70
% Open Area	36				
Strip Test, 1" wide ASTM D-1682 Warp/Fill (lb/in) Elongation, %	186/150 23/11			100 80	350/275 27/29
Grab Test ASTM D-1682 Warp/Fill (lb/in) Elongation, %			50/50 70/70		
Oregon State U. Ring Test, lb/in Wet/Dry @ 12 in/min. % Elongation Wet/Dry				68.0/60.0 101.0/50.0	
Burst, lb.	437			160	545
Seam Strength, lbs/in	90				
Abrasion Resistance, lbs. after 1000 cycles					
Width, ft.			6 or 12	15	
Length, ft.			300	300	
				$K = 6x10^{-2}$ cm/sec.	

Table 7-1 (continued)

MANUFACTURER OR SUPPLIER	MONSANTO TEXTILES COMPANY				
Trade Name	Bidim C 22	Bidim C 28	Bidim C 34	Bidim C 38	Bidim C 42
Construction	Nonwoven, Spunbonded polyester, Needlepunched				
Thickness, Mils	75	95	109	114	188
Weight, $^{oz}/_{yd^2}$ ($^{gm}/_{m^2}$)	4.5 (150)	5.9 (200)	9.6 (325)	12.4 (420)	19.4 (657)
Equivalent opening Size (EOS) U. S. Standard Sieve	80	80	80	80	80
% Open Area					
Strip Test, 1" Wide ASTM D-1682 Warp/Fill (lb/in) Elongation, %					
Grab Test ASTM D-1682 Warp/Fill (lb/in) Elongation, %	110	213	234	290	582
Oregon State U. Ring Test, lb/in Wet/Dry @ 12 in/min. % Elongation Wet/Dry	60.0/60.0 44.0/44.0	84.0/84.0 63.0/63.0		130.0/130.0 50.0/50.0	
Burst, lb. ASTM-D751	225	397	422	503	864
Seam Strength					
Abrasion Resistance, lbs. after 1000 cycles					
Width, ft.	13.8-17.4	13.8-17.4	13.8-17.4	13.8-17.4	13.8-17.4
Length, ft.	990	990	990	990	462

Table 7-1 (continued)

MANUFACTURER OR SUPPLIER	CARTHAGE MILLS, INC.			ADVANCE CONSTRUCTION SPECIALTIES	
Trade Name	Filter-X	Poly-Filter X	Poly-Filter GB	LECC Type A	LECC Type B
Construction	Woven, Vinylidene Chloride	Woven, Polypropolene	Woven, Polypropolene	Woven, Polypropolene, Monofilament yarn	Woven, Polypropolene Monofilament yarn
Thickness, Mils	15	16.8	26	17	22
Weight, $^{oz}/_{yd^2}$ ($^{gm}/_{m^2}$)	11.6 (390)	7.2 (244)	6.6 (225)	7.2 (244)	6.3 (213)
Equivalent opening Size (EOS) U. S. Standard Sieve	100	70	40	100	40
% Open Area	4.6	5.2	24.4	4.3	26
Strip test, 1" wide ASTM D-1682 Warp/Fill (lb/in)	206/113	388/257	208/202		
Elongation, %	22/27	22/27	24/17		
Grab Test ASTM D-1682 Warp/Fill (lb/in)	200/110	380/220	200/200	399/244	280/232
Elongation, %				33/33	40/42
Oregon State U. Ring test, lb/in @ 12 in/min. % Elongation					?
Burst, lb	268	542	625	528	528
Seam strength	80	195	160	198	198
Abrasion resistance, lbs. after 1000 cycles	57/9	100/70	161/162		
Width, ft.	6-84 in 6' mult.	6-84 in 6' mult.	6-84 in 6' mult.	6-84 in 6' mult.	6-84 in 6' mult.
Length, ft.	50 - 1200	50 - 900	50 - 1200		

Table 7-1 (continued)

MANUFACTURER OR SUPPLIER	STAFF INDUSTRIES				
Trade Name	M-1192	PERMEALINER M-1195	M-1196	M-1197	
Construction	Woven Polypropylene				
Thickness, mils					
Weight, oz/yd^2 (gm/m^2)	6.8 (236)	7.2 (252)	7.2 (252)	7.2 (252)	
Equivalent opening size (EOS) U. S. standard sieve	30-50	70-100	50-100	30-100	
% Open Area	9-15	4-10	4-15	4-20	
Strip test, 1" wide ASTM D-1682 Warp/Fill (lb/in) Elongation, %	350/240 36/26	400/280 34/32	350/220 34/32	325/210 34/32	
Grab Test ASTM D-1682 Warp/Fill (lb/in) Elongation, %					
Oregon State U. Ring test, lb/in @ 12 in./min. % Elongation					
Burst, lb ASTM-D751	465	510	500	450	
Seam Strength					
Abrasion resistance, lbs. after 1000 cycles		80	80	75	
Width, ft.					
Length, ft.					

Table 7-1 (continued)

MANUFACTURER OR SUPPLIER	Staff Industries		Gulf States Paper Corp.	Advance Construction Specialies	
Trade Name	Permealiner		Hold/Gro	Polyfelt TS 300	
Construction	Needle-Punched		Polypropylene yarn with paper filler	Nonwoven	
Thickness, mils				127	
Weight, oz/yd^2 ($^{gm}/m^2$)	4 (140)	8 (280)	2.8 (98)	7.8 (273)	
Equivalent Opening size (EOS) U. S. standard sieve	120	100			
% Open Area					
Strip Test, 1" wide, ASTM D-1682 Warp.Fill (lb/in)	80/60	150/140			
Elongation, %	20/30	12/11			
Grab Test ASTM D-1682 Warp/Fill (lb/in)				227	
Elongation, %				101	
Oregon State U. Ring Test, lb/in @ 12 in/min. % Elongation					
Burst, lb ASTM-D751	143	400			
Seam Strength				236	
Abrasion resistance, lbs. after 1000 cycles					
Width, ft.	15	4.75	5 & 10	Multiples of 8.17	
Length, ft.			360	787	

Table 7-1 (continued)

Table 7-2: Summary of Results of Fabric Tension Tests (Modified Cut Strip Tests)

Type of Fabric	Std. Dev. (Dry)	Average Strength		% Elongation		Std. Dev. (Dry)	Direction
		Dry	Wet	Dry	Wet		
Fibertex 320	6.93	98.9 lb/in	122.5 lb/in	183%	209%	13.04	Warp
Fibertex 320	2.00	121 lb/in		161.8%		17.54	Fill
Fibertex 420	6.08	97.0 lb/in		168%		19.66	Warp
Fibertex 420	6.19	123 lb/in		143%		0.0	Fill
Bidim 4 oz.	11.20	77.1 lb/in	62.5 lb/in	49%	32%	14.19	Warp
Bidim 4 oz.	2.85	48.4 lb/in	51.3 lb/in	59.3%	67%	5.91	Fill
Bidim 6.8 oz	13.71	89.6 lb/in		47%		5.68	Warp
Bidim 6.8 oz	6.86	45.1 lb/in	50.0 lb/in	48.5%	67%	5.17	Fill
Bidim 12 oz.	5.77	166.6 lb/in	209.8 lb/in	51.5%	77%	3.00	Warp
Bidim 12 oz.	5.08	124.0 lb/in	105.5 lb/in	71.5%	63%	8.85	Fill
Mirafi 140	2.17	40.7 lb/in	39.8 lb/in	87.2%	85%	14.10	Warp
Mirafi 140	4.68	32.7 lb/in	30.0 lb/in	68%	68%	10.12	Fill
Phillips (Supac)	2.49	32.3 lb/in	31.0 lb/in	54.2%	58%	10.01	Warp
Phllips (Supac)	8.11	42.3 lb/in	40.5 lb/in	45.2%	47%	4.43	Fill
Typar	2.22	33.0 lb/in	30.0 lb/in	30.8%	18%	2.21	Warp
Typar	4.10	50.0 lb/in	52.3 lb/in	45.5%	53%	6.61	Fill

These tests were conducted on 4-inch wide samples, with a loading rate of 12 in/min. An average of five tests were run on each type of fabric. The samples were run in the warp and fill direction. The Fibertex samples were run with a jaw size opening of 2 inches because of lack of stroke; all the other samples were run with the standard jaw size opening of 3 inches.

Table 7-3: Summary of Results of Sewn Seam Testing.

Type of Fabric		Average Strength	Std. Deviation	% Elongation	Std. Deviation
Phillips (Supac)	4 oz/yd^2	24.31 lb/in	1.78	78.5%	5.07
Mirafi 140	4 oz/yd^2	27.58 lb/in	1.27	70.0% T	13.43
Typar	4 oz/yd^2	41.44 lb/in	2.84	56.0%	8.04
Bidim	4 oz/yd^2	43.10 lb/in 1/	3.99	71.0% 1/	2.94
Bidim	6.8 oz/yd^2	52.31 lb/in*	1.95	37.5%*	3.32
Bidim	12 oz/yd^2	55.75 lb/in*	0.61	37.5%*	1.91
Fibertex 320	9 m/m^2	58.88 lb/in*	4.60	127.5%*	21.65
Fibertex 420	9 m/m^2	68.94 lb/in*	1.74	62.8%*	7.32

1/ Stitches failed with a load above 47.5 lbs/in.

* Threads snapped but fabric did not fail.

T Wet strength shows 88% of dry strength; all others were about the same wet or dry.

This testing was run on 4-inch wide samples except for 6 inches wide in Mirafi, with a loading rate of 12 in/min. An average of five tests were run on each type of fabric. All samples were run in warp direction.

Table 7-4: Summary of Strength Tests on Asphalt Coated and Uncoated Fabrics after Eighteen Months Field Exposure at Shelton, Washington.

Type of Fabric	Coating	Average Strength	Average % Elongation
Bidim 6.8 oz.	Asphalt	100 lbs/in	42%
Bidim 6.8 oz	No Coating	*43.5 lbs/in	*40%
Bidim 12 oz.	Asphalt	128 lbs/in	108%
Bidim 12 oz.	No Coating	Sample Disintegrated	
Fibertex 320	Asphalt	80.6 lbs/in	121%
Fibertex 320	No Coating	Sample Disintegrated	
Fibertex 420	Asphalt	133.5 lbs/in	+200%
Fibertex 420	No Coating	Sample Disintegrated	

* 48.5% strength (lbs/in) retained after exposure for 18 months.

85.1% Elongation (%) retained after exposure for 18 months.

Notes: These tests were run on the fabrics with approximately 18 months of exposure at the site of the Shelton test wall.

These tests were conducted on 4-inch wide samples, with a loading rate of 12 in/min.; an average of five tests were run on each type of fabric. It was impossible to tell the direction of these fabrics.

CHAPTER 8: MANUFACTURERS' LITERATURE AND COSTS

Table 8-1 is a list of the manufacturers' literature and reference material included in the "Fabrics in Construction" reference notebooks to be distributed in June 1977. Table 8-2 lists where to obtain the items listed in Table 8-1 to aid readers of this report in establishing a fabrics reference notebook.

Table 8-3 summarizes the primary usage, description, installation instructions, limitations, and product information source for each fabric. This information was obtained primarily from manufacturers' brochures and data sheets.

COST FACTORS

When using fabrics or any other new material or concept, two cost factors are important:

1. Cost of materials and installation.
2. Cost and benefit of the new method or material compared to the conventional one.

We planned, early in the preparation of this report, to include the current price of all fabrics listed in Table 7-1. We found over the last three years that fabric prices are very dependent on market conditions or supply, demand, and competition. For example, one of the woven fabrics cost \$0.15 per ft.^{2} in 1974, \$0.22 per ft.^{2} in 1975, and \$0.12 per ft.^{2} in late 1976. Non-woven fabrics quoted at \$0.08 per ft.^{2} before the Quinault test road installation are now quoted at \$0.06 to \$0.07 per square foot.

The short supply of woven filter fabrics during early phases of the Alaska oil pipeline construction caused prices to increase and forced users to explore other fabrics, primarily the non-wovens. The U. S. Army Corps of Engineers, Vicksburg Waterways Experiment Station, did some limited testing to develop design criteria and specifications similar to those developed earlier for woven plastic filters. The gradient ratio test and revised guide specification (October 1976) resulted from this work (9).

The testing was not as complete as earlier testing and did not include the wide range of fabrics on the market. Because of the limited testing and the wide variation in soil properties in the Northwest, we recommend restricting the use of non-woven fabrics for filtration to non-critical locations without severe seepage conditions. Non-woven fabrics should be used for filtration only after a gradient ratio test has been performed for each soil-fabric combination planned.

Many of the fabric manufacturers, particularly the non-wovens, got into the Civil Works market within the last one to five years. They entered the market to expand their markets and competition from new products. Many of the non-wovens have replaced jute and woven fabrics for carpet backing, furniture undercovering, and throw-away clothing.

The fabrics manufacturers have contributed greatly to our knowledge of the uses of fabrics in construction; much work still needs to be done to understand and rationally design fabrics installations. Competition between fabrics manufacturers and increased knowledge will improve economic projections for fabric users.

COSTS

Fabric installation costs can be estimated using established cost estimating techniques and guides. Figure 8-1 contains approximate materials and installation costs for several fabrics and uses.

Figure 8-2 contains three alternative designs for a five-foot deep underdrain to remove ground water. Alternative one and three carry the water in two-foot wide open gravel; protected by graded filter and plastic filter cloth, respectively. Alternative two uses a graded filter and perforated pipe. These three alternatives would be equal for many of the underdrains constructed in fine-grained soils in Region 6. The cost savings of $5 to $22 per foot of installed drainage is very significant; the $5 figure assumes 100% effectiveness of all drains and the $22 figure assumes 50% effectiveness of the conventional drains and 100% effectiveness of filter cloth drains.

Figure 8-3 contains a chart for calculating the cost saving of separation layers. To use the chart, enter with the inches of contamination saved, go vertically to intersect the line for the appropriate rock cost and lane width, and then horizontally to the total cost per lane mile of the aggregate saved. Deducting the fabric cost will yield the dollar saving per lane mile. For an 18-foot subgrade, $10 per cubic yard aggregate, and $0.12 per square foot of fabric, the net savings per lane mile would be $2,200 for four-inch aggregate savings and $8,060 for six inches of aggregate.

Use of fabrics for subgrade restraint in the Quinault area of Washington has resulted in a reduction of pit run rock required from 200 cubic yards per station without fabric to 137 cubic yards per station with fabric.

The amount of rock was further reduced to 120 cubic yards per station by crushing to minus six inch size. For rock costs of $5 and $6 per cubic yard for pit run (shot) in place, the savings is $7,000 to $11,000 per mile. For rock crushed to minus six inch size at $5.50 to $6.50 per cubic yard, the net savings per mile is $8,500 to $15,800 per mile.

Retaining walls using fabrics are estimated to cost $11.70 per square foot installed, about $6.00 per square foot less than conventional walls of similar size. In addition to the cost savings, the walls are easy to build and adjust to the site during construction. More work needs to be done to determine working strength of the materials used.

Erosion control and waterproofing cost savings are not easily estimated. Most erosion from road construction and reconstruction occurs during construction and the first year after construction.

One of the main factors leading to rapid deterioration of pavement structures is high moisture conditions, often due to uncontrolled surface infiltration (5, 6). Although their use is difficult to evaluate economically, fabrics can be used positively to control erosion and to waterproof pavements, greatly reducing the uncertainty of performance.

COST SUMMARY

The use of new materials and techniques always involves an element of risk. This risk can be greatly reduced through a program of testing and evaluation prior to their adoption for general usage.

Potential annual cost savings by using fabrics in road construction in Region 6 of the Forest Service as shown in Figure 8-4 are impressive.

Even more impressive is the fact that the fabric installations are protecting facilities worth hundreds of times these potential savings.

The potential savings, the cost of the protected facilities, and the always present risks justifies a program of testing and evaluating fabrics uses and installations to increase the potential and reduce the risk.

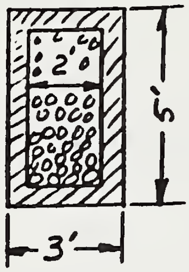
Cooperation of all users in following the "trial use" and "special use" concept will help speed up the movement of fabric uses into "general use" with valid guidelines and specifications. Reporting performance of installations using the "Fabrics Use Report Sheet"(Figure 8-5) will greatly aid this process.

Figure 8-1 Materials and Installation Costs for Fabrics

FABRIC OR USE	MATERIAL	INSTALLATION			
	4 oz/yd^2	$\leq$ 5' Trench	> 5'	Slope	Subgrade
WOVEN	\$0.12— 0.25/ft^2	\$0.10— 0.10/ft^2	\$0.10— 0.25/ft^2	\$0.03— 0.045/ft^2	\$0.02— 0.035/ft^2
	1.08 2.25/yd^2	0.63 0.90/yd^2	0.90 2.25	0.30 0.40/yd^2	0.18 0.32/yd^2
NONWOVEN 4 oz/yd^2	0.05 0.08/ft^2	Same as Woven			
	0.45 0.72/yd^2				
12 oz/yd^2	0.15 — 0.24/ft^2	25% increase over 4 oz/yd^2			
	1.35 — 2.16/yd^2				
EROSION CONTROL	0.055/ft^2 0.50/yd^2			0.30— 0.045/ft^2 0.30— 0.40/yd^2	
WATERPROOFING AND PAVEMENT REINFORCEMENT	Same as nonwoven plus 0.25 to 0.30 gal/sy residual asphalt				
REINFORCEMENT (WALLS)	2.50/ft^2	Excavation 3.35	Backfill 3.35	Labor 2.50	Total \$11.70

(Cost per ft^2 wall face)

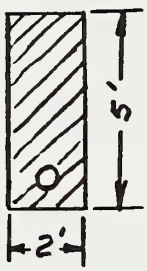
Alternate No. 1: Open drain rock with graded sand filter·



Costs: Excavation 55.5 CY @ \$10.00 = 555
Graded Sand 25.9 CY @ \$20.00 = 518
Drain Rock 29.6 CY @ \$20.00* = 592
\$1665/100 ft.
or \$16.65/L.F.

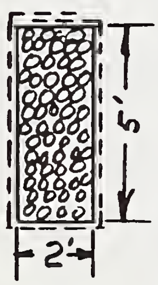
*High installation cost.

Alternate No. 2: Graded rock filter with perforated pipe.



Costs: Excavation 37 CY @ \$10.00 = 370
Graded Rock 37 CY @ \$20.00 = 740
Pipe 100 ft. @ \$6.00 = 600
\$1710/100 ft.
or \$17.10/L.F.

Alternate No. 3: Open Drain Rock with plastic filter cloth.



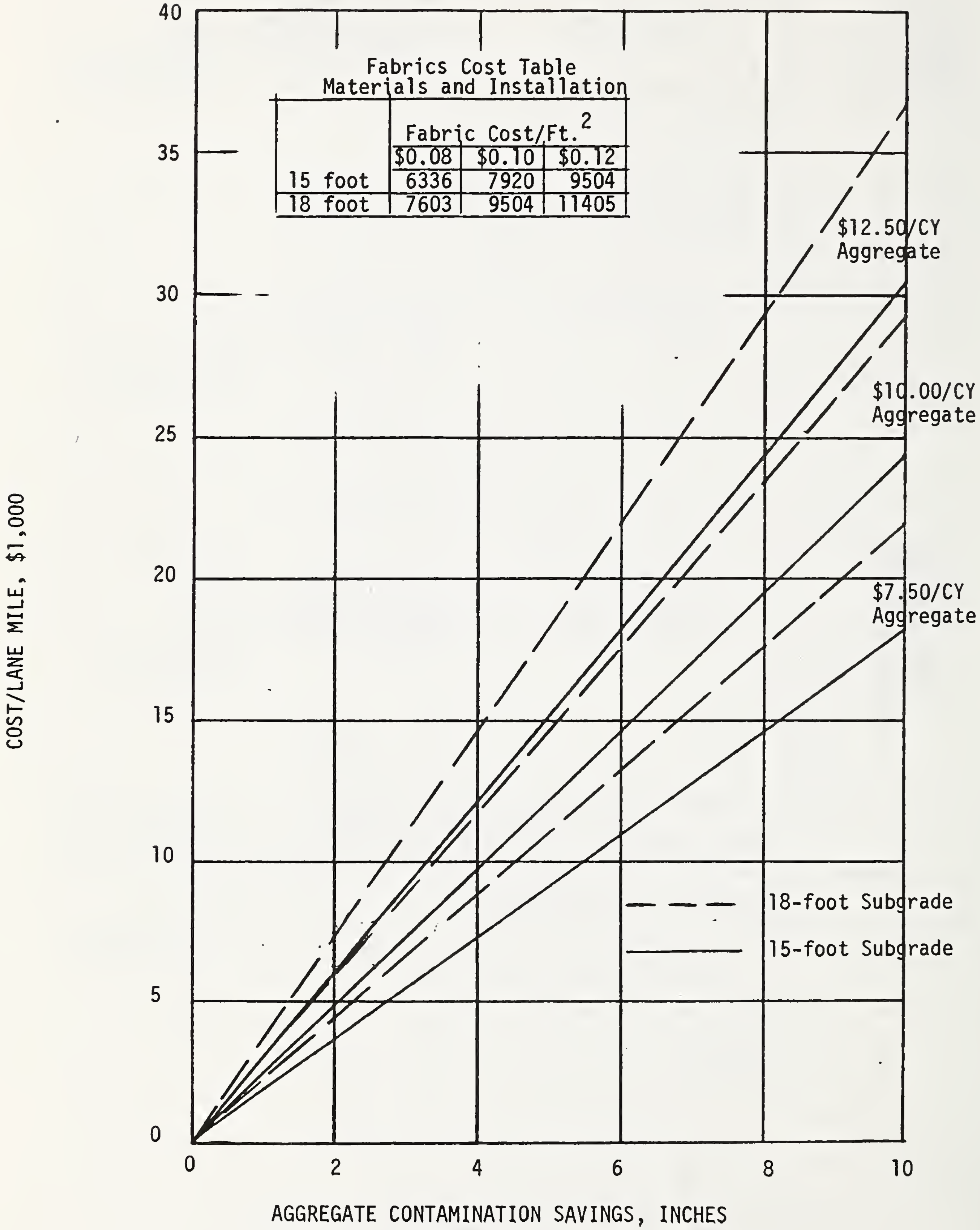
Costs: Excavation 37 CY @ \$10.00 = 370
Drain Rock 37 CY @ \$10.00 = 370
Filter Cloth 1600 ft^2 @ \$0.22 = 352
\$1092/100 ft.
or \$10.92/L.F.

Summary of Savings Using Filter Fabrics, Alternate No. 3

Alternate	Alt. 1 & 2 100% Success		Alt. 1 & 2 50% Success	
	Cost/Ft.	Saving/Ft.	Cost/Ft.	Saving/Ft.
1	\$16.65	\$4.99	\$33.30	\$21.64
2	\$17.10	\$5.44	\$34.20	\$22.54
3	\$10.92	- -	\$10.92	- -

Figure 8-2: Costs of Alternative Trench Drains

Figure 8-3: Chart for Calculating Economics of Subgrade Separation



Fabrics Cost Table
Materials and Installation

	Fabric Cost/Ft.^{2}		
	$0.08	$0.10	$0.12
15 foot	6336	7920	9504
18 foot	7603	9504	11405

FIGURE 8-4

Potential Saving Using Fabrics
In Region 6, Forest Service

		Range of Savings	
FILTRATION (ground water only, less than 5 feet deep)			
1200 mile/yr. @ 100 LF/mile = 120,000 LF/YR.			
	@ $5/LF	$600,000	
	@ $22/LF		$2,640,000
SEPARATION			
600 lane mile/yr.			
	4 inch rock saving @ $2200/lane mile	1,320,000	
	6 inch rock saving @ $8060/lane mile		4,836,000
SUBGRADE RESTRAINT			
200 mile/yr.			
	@ $7,000/mile	1,400,000	
	@$15,800/mile		3,160,000
EARTH REINFORCEMENT			
50,000 to 100,000 FT^2 face/yr.		300,000	
	@ $6/ft^2		600,000
	TOTAL*	$ 3,620,000-	$11,236,000

*Does not include:

-Filters for rock buttress, trenches over 5 feet deep or structures.

-Erosion Control

-Pavement waterproofing, drainage, or reinforcement.

Figure 8-5 Fabrics Use Report Sheet

Forest__________________________ Type of Project________________________________
(Road, Trail, Buildings)

Location_________________________ Date Construction Completed____________________

Reason Fabric was used:

Function: P = PRIMARY S = SECONDARY

________ Filtration
________ Separation
________ Subgrade Restraint
________ Water Proofing
________ Earth Reinforcement
________ Erosion Control
________ Other

Construction: Timber Sale______, Public Wks. ______, Force Acct.________

Cost:	With Fabric	Without Fabric
Unit Price	______________________	______________________
Total Project	______________________	______________________
Net Saving	______________________	

Fabric Data:

Quantity Used_________________________ Weight____________________ oz/yd^2
Trade Name _________________________ Cost ________________________

Performance Compared to that Predicted:

Less than __________ Equal to _________ Better than __________

Design Criteria Adequacy ____

Specification Criteria Adequacy ____

Remarks: Attach separate sheet

Attach typical sections, specifications, photos, test data, sketches, diagrams, etc.

TABLE 8-1

Manufacturers' Literature and Reference Material included in R-6 Reference Notebook, April, 1977.

Chapter 1 - Introduction

1-1* Plastic Filter Cloth - Some questions and answers, by John E. Steward

Chapter 2 - Filtration

2-1 Regional Specification 6-47, Plastic Filter Cloth.

2-2 Use of Woven Filter Cloth As A Replacement for Graded Rock Filters by John E. Steward.

2-3 Civil Works Construction Guide Specification for Plastic Filter Cloth, CW-02215.

2-4 Mechanism of Filtration in Subsurface Drains Designed With Mirafi 140 Fabric, PM-3.

2-5 Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths by Charles C. Calhoun**.

* Numbers refer to address on Table 8-2 where additional copies can be obtained.

** A charge is made for these references.

Chapter 3 - Separation

3-1 Constructing Access Roads With Mirafi 140 Fabric, PM-6.

3-2 Proposal For Trial Use of Nonwoven Fabrics on Moderate Strength Road Subgrades.

Chapter 4 - Subgrade Restraint

4-1 Proposal for Trial Use of Nonwoven Fabrics on Low Strength Road Subgrades.

4-2 Polyfelt TS300 Fabric in Civil Engineering

Chapter 5 - Earth Reinforcement

5-1 Fabric Retained Earth Walls by J.R. Bell, Alan N. Stilley, and Bruce Vandre.

Table 8-1 (Page 2)

Chapter 6 - Erosion Control

6-1 Hold/GRO Erosion Control Fabric

6-2 Eliminate Water-caused Soil Erosion,
Specify: Poly-Filter X, Filter-X, Poly-Filter GB.

6-3 Filter Handbook.

6-4 Erosion and Siltation Control With Mirafi 140 Fabric, PM-7.

Chapter 7 - Physical Properties

7-1 Mirafi 140 Construction Fabric.

Chapter 8 - Manufacturers Literature - Costs

8-1 Staff Industries.

8-2 TYPAR

8-3 Mirafi 140 Fabric for Ground Stabilization and Drainage Applications, TBM2.

8-4 Advance Construction Specialties Co., Inc.

8-5 Laboratory Testing of Laurel Erosion Control Cloth for Advance Construction Specialties Co., Memphis, Tennessee by Soil Testing Services, Inc.*.

8-6 Bidim-Engineering Fabric for Soil Stabilization and Drainage.

8-7 Protect Supporting Soils - Specify Monofilter.

* A charge will be made for this reference.

Chapter 9 - Other Uses

9-1 Petromat Fabric.

9-2 Tips From "Petro Pete" on the Use of Petromat Fabric in Road Paving Applications.

9-3 Phillips Paving Products.

TABLE 8-2

Address list, sources of manufacturer's literature and reference material in Reference Notebook, April, 1977.

Advance Construction Specialties Co., Inc.
Post Office Box 17212
Memphis, Tennessee 38117
Phone: 901-362-0980
Article 8-4, 4-2

Carthage Mills Incorporated
Erosion Control Division
124 W. 66th. Street
Cincinnati, Ohio 45216
Phone: 513-242-2740
Article 6-2, 6-3

Celanese Fibers Marketing Co.
1211 Avenue of the Americas
New York, N.Y.10036

Representative:
Wiley-Bayley Inc.
3310 Meridian Avenue N.
Seattle, WA 98103

Contact:
Dedrik A. Voss, P.E.
Mgr. Mirafi Systems
Article 2-4, 3-1, 6-4, 7-1, 8-3

E. I. DuPont
Textile Fibers Department
Center Road Building
Wilmington, Delaware 19898

Contact:
Dick Hutchins or E.I. DuPont
Suite 601, 400 Bldg., 400 108 Street N.E.
Bellevue, WA 98004
Phone: 206-455-4500
Walter E. Partridge
Articles 8-2

Gulf States Paper Corporation
P.O. Box 3199
Tuscaloosa, Alabama 35401
Phone: 205-553-6200
Article 6-1

Table 8-2 (Page 2)

Headquarters Department of the Army
(DAEN-CWE-SS)
Washington D. C. 20314
Article 2-3

Menardi-Southern - Soil and Erosion Control Dept. Headquarters
3908 Colgate
Houston, Texas 77017
Phone: 713-643-6513
Article: 8-7

Monsanto Textiles Company
800 N. Lindberg Blvd.
St. Louis, MO 63166

Contact:
Robert M. Parks
Project Manager
Nonwoven Business Group
Phone: 314-694-1000
Article 8-6

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22151
Article 2-5

Phillips Fibers Corporation
Representative:
Robert H. Manz, P.E.
District Sales Engineer
17301 N. E. 4th.
Redmond, WA 98052
Phone: 206-883-0316
Articles 9-1, 9-2, 9-3

Soil Testing Services, Inc.
111 Pfingsten Road
Northbrook, Ill. 60062
Phone: 312-272-6520
Article 8-5

Staff Industries
78 Dryden Road, P.O. Box 797
Upper Montclair, New Jersey 07043
Phone: 201-744-5367
Article 8-1

USDA Forest Service
Post Office Box 3623
Portland, OR 97208
Attention: John E. Steward
Phone: 503-221-2413
Articles 1-1, 2-1, 2-2, 3-2, 4-1, 5-1

Table 8-3

BIDIM

PRIMARY USAGE:

As a roadbuilding material, provides subgrade restraint and separation of poor soils from fill material. Can be used in fabric wall construction and silt fences for erosion control.

DESCRIPTION:

Bidim is a continuous filament polyester fiber needled to provide mechanical interlocking. The fabric is decay resistant and withstands chemical attack from acid or alkaline soils.

Manufactured in the following dimensions:

	C 22	C 28	C 34	C 38	C 42
Weight oz/yd^2	4.5	5.9	9.6	12.4	19.4
(gm/m^2)	150	200	325	420	650

Widths are 4.2m and 5.3m (166 and 209 inches). Rolls come in 300m (300 yard) lengths except C 42 which comes in 150m (154 yard) lengths.

INSTALLATION INSTRUCTIONS:

Clear as per normal road construction and fill in ruts and surface irregularities deeper than 75 or 100 mm (3 or 4 inches). Roll out fabric in the direction of the roadway, laying it directly on the soil. Spread and compact the fill material keeping truck wheels and dozer off the bare fabric. For wide roads, the centerline fabric joint can be sewn or overlapped. Lapped joints should have 0.6m (2 feet) of overlap.

LIMITATIONS:

The polyester fabric degrades under prolonged exposure to ultraviolet light.

PRODUCT INFORMATION SOURCES:

Monsanto Textiles Company
Nonwoven Business Group - G4WC
800 N. Lindberg Blvd.
St. Louis, MO 63166
(Telephone 314-694-7179 or 694-6355)

Table 8-3 (cont.)

FIBERTEX

PRIMARY USAGE:

Used as a separation barrier to isolate two sets of soil or aggregate particles. As a restraint layer, redistributes stress by transference along the membrane.

DESCRIPTION:

Fibertex is a nonwoven fabric made from 100% polypropylene filament fibers. Fibertex is manufactured in the following dimensions: 420 grams per square meter (12.5 ounces per square yard), 140 feet (43m) in length, 320 grams per square meter (9-1/2 ounces per square yard), 180 feet (55m) in length, 600 grams per square meter (17-1/2 ounces per square yard), 100 feet (30m) in length. All weights are manufactured in widths of 208 inches (5.3m).

INSTALLATION INSTRUCTIONS:

Sharp objects should be removed from the area to be stablized to avoid fabric punctures. Keep at least one foot of aggregate between the fabric and truck tires. If the fabric is damaged during construction, a patch can be made using fibertex and a standard overlap of one to two feet.

LIMITATIONS:

Will degrade with exposure to sunlight. Where such exposure is necessary, the fabric should be coated with an asphalt emulsion.

PRODUCT INFORMATION SOURCES:

Crown Zellerbach Corp.
Nonwoven Fabrics Division
P. O. Box 877
Camas, WA 98607
Contact: Dick Hoefer (206/824-4444, Ext. 141)

Table 8-3 (cont.)

FILTER-X

PRIMARY USAGE:

Used as a replacement for graded filter systems and filter blankets for drainage systems. Also used for erosion control.

DESCRIPTION:

Filter-X is a cloth woven from polyvinylidene chloride resin monofilament yarn. It has a thickness of 15 mils (0.015 inch) and weighs 12 oz/yd^2 (407 gm/m^2). Filter-X is not affected by salt water, bacterial decay or weathering. The equivalent opening size (EOS) is 100 mesh with 4.6% open area.

Manufactured in 1.8m (6 foot) widths and multiples thereof up to 25.6m (84 feet) and lengths from 15.2m to 274m (50 ft. to 900 ft.) depending upon the width. Supplied with grommets for securing purposes.

INSTALLATION INSTRUCTIONS:

Each specific site may require some modification or variation of the general criteria listed below. Manufacturer, technical representatives or specialists experienced in the use of this product should be consulted for guidance. In general, the material is rolled out onto the prepared surface and secured with specially designed pins, staples, or rods. Where more than one sheet is required, they should be lap jointed to insure continuous coverage of the area to be protected. When in place, the succeeding layer of materials, i.e., gravel, rock, can be placed on the filter sheet. Heavy and/or sharp material should be placed with care in order that the integrity of the sheet can be maintained.

LIMITATIONS:

Both tensile strength and abrasion resistance are lower than for the polypropylene cloths; therefore, use of Filter-X should be limited to structures not requiring high tensile strength and abrasion resistance, such as French drain systems or behind bulkheads.

PRODUCT INFORMATION SOURCE:

Carthage Mills, Inc.
Erosion Control Division
124 W. 66th Street
Cincinnati, OH 45216
Telephone 513-242-2740

Table 8-3 (cont.)

LAUREL EROSION CONTROL CLOTH (LECC)

PRIMARY USAGE:

Used as a replacement for graded filter systems and filter blankets for drainage systems and for erosion control.

DESCRIPTION:

LECC is a cloth woven from polypropylene monofilament yard. Two types are made: Type A, weighing 244gm/m^2 (7.2 oz/yd^2) and 0.017 inches (17 mils) thick with 100 mesh EOS and 4.3% open area, and Type B, weighing 213 gm/m^2 (6.3 oz/yd^2) and 0.022 inches (22 mils) thick with 40 mesh EOS and 26% open area. Neither type is affected by salt water, bacterial decay or weathering.

Manufactured in 1.8 m (6 foot) widths and multiples thereof up to 25.6m (84 feet) and lengths from 15.2m to 274m (50 feet to 200 feet). Special sizes can be fabricated upon request. Supplied with grommets for securing purposes.

INSTALLATION INSTRUCTIONS:

Each specific site may require some modification or variation of the general criteria listed below. Manufactuer, technical representatives or specialists experienced in the use of this product should be consulted for guidance. In general, the material is rolled out onto the prepared surface and secured with specially designed pins, staples or rods. Where more than one sheet is required, they should be lap jointed to insure continuous coverage of the area to be protected. When in place, the succeeding layer of materials, i.e., gravel, rock, can be placed on the filter sheet. Heavy and/or sharp material should be placed with care in order that the integrity of the sheet can be maintained.

PRODUCT INFORMATION SOURCE:

Advance Construction Specialties Co.
1050 Texas Street
Memphis, TN 38106
Telephone PL 901-775-1611

Table 8-3 (cont.)

POLYFELT TS 300

PRIMARY USAGE:

Used as a separation barrier to isolate two sets of soil or aggregate particles. As a restraint layer, redistributes stress by transference along the membrane. Can be used in fabric wall construction and silt fences for erosion control.

DESCRIPTION:

Polyfelt is a nonwoven, continuous filament fabric. It is manufactured in widths of 8 feet 2 inches by 787 feet in length (2.5m x 240m). Wider rolls can be ordered in multiple widths of 8 feet 2 inches by length up to 787 feet. However, total square footage can not exceed 10,000 square feet (930m^2). Weight is 7.7 ounces per square yard (260 gm/m^2).

INSTALLATION INSTRUCTIONS:

For subgrade support and restraint, clear as per normal construction removing all vegetative material and filling in ruts exceeding 2 to 3 inches (50 to 75mm) in depth. Lay the fabric by rolling out in a direction parallel to the centerline. The fabric can be joined by overlapping, pinning, or welding as per the manufacturer's instructions. Fill material can be placed directly on the fabric; however, truck wheels and dozers should be kept off the bare fabric.

LIMITATIONS:

None stated in the Manufacturer's literature.

PRODUCT INFORMATION SOURCE:

Advance Construction Specialties
P. O. Box 17212
Memphis, TN 38117
Telephone 901-362-0980

Table 8-3 (cont.)

PETROMAT

PRIMARY USAGE:

Used as a pavement overlay material to reduce overlay thickness, prevent reflection cracking, and seal pavement surface. Also, used as a waterproofing membrane on bridge decks.

DESCRIPTION:

Petromat is a nonwoven polypropylene mat designed to hold about 0.2 gallons per square yard of asphalt.

Petromat is manufactured in 90m (300 feet) rolls either 1.9 or 2.8m (75 or 150 inches) wide.

INSTALLATION INSTRUCTIONS:

Clean cracks and road surface of dirt, dust and vegetation, and fill all cracks 3 to 4mm (1/8 to 1/4 inch) or larger and all holes. Apply asphalt binder course at 0.25 to 0.3 gallons per square yard. Unroll fabric over asphalt binder and construct overlay. Hotmix temperature should not exceed 325° F.

For seal coats, the asphalt binder should be applied at 0.10 gallons per square yard residual asphalt, allowing for adequate cure time before laying fabric. Quantity of second binder course should include 0.1 gallon per square yard residual asphalt for the fabric absorption in addition to whatever is required to retain the aggregate.

LIMITATIONS:

Asphalt temperatures should not exceed 325° F. to prevent shrinkage and damage to the fabric.

PRODUCT INFORMATION SOURCE:

Phillips Petromat
Western Region
3031 Tischway, Suite 735
San Jose, CA 95128
Telephone 408-247-2801

Table 8-3 (cont.)

MIRAFI 140

PRIMARY USAGE:

Used as a separation barrier to isolate two sets of soil or aggregate particles. As a restraint layer, redistributes stress by transference along the membrane.

DESCRIPTION:

Mirafi 140 is a nonwoven fabric constructed from two types of continuous filament fibers. One is entirely polypropylene while the other is a polypropylene core encased in a nylon sheath.

Mirafi 140 has a thickness of 30 mils (0.03 inches) and weighs 4 oz/yd^2 ($140 gm/m^2$).

Manufactured in 4.5m (14 feet 9 inches) widths and 100m (328 feet) lengths.

INSTALLATION INSTRUCTIONS:

Sharp objects should be removed from area to be stablized to avoid fabric punctures. Keep at least one foot of aggregate between fabric and truck tires. If the fabric is damaged during construction, a patch can be made using Mirafi 140 and a standard overlap of .3 to 1 meter.

LIMITATIONS:

It is not significantly affected by alkalines and weak acids (PH 3). Sustained exposure to strong acids and phenalic compounds or sunlight can cause fabric property deterioration.

PRODUCT INFORMATION SOURCE:

Celanese Fibers Marketing Company
1211 Avenue of the Americas
New York, NY 10036
Telephone212-764-7640

Table 8-3 (cont.)

POLYFILTER GB

PRIMARY USAGE:

Use as a replacement for graded filter systems in filter blankets or drainage systems. Also used for erosion control.

DESCRIPTION:

Polyfilter GB is cloth woven from polypropylene monofilament yard. It has a thickness of 26 mils (0.026 inches) and weighs 6.6 ounces per square yard (225 grams per square meter). Polyfilter GB is not affected by salt water, bacterial decay, or weathering. The equivalent opening size is 40 mesh with 21 to 26 percent open area.

Manufactured in 1.8 meter (6 foot) widths and multiples thereof up to 25.6 meters (84 feet) in lengths from 15.2 meters to 274 meters (50 feet to 1,200 feet) depending upon widths. Supplied with grommets for securing purposes.

INSTALLATION INSTRUCTIONS:

Each specific site may require some modification or variation of the general criteria listed below:

Manufacturer, technical representative or specialist experienced in the use of the product should be consulted for guidance. In general, the material is rolled out onto the prepared surface and secured with specially designed pins, staples or rods. Where more than one sheet is required, they should be lap jointed to ensure continuous coverage of the area to be protected. When in place, the succeeding layer of materials, i.e. gravel, rock, can be placed on the filter sheet. Heavy and/or sharp materials should be placed with care in order that the integrity of the sheet can be maintained.

LIMITATIONS:

Stones weighing up to 133 kg (250 pounds) may be dropped from 0.9 meters (3 feet) without damage to the cloth. Subsequent layers may be dropped from greater heights, but never more than about 8 meters (10 feet). In no case should stones weighing over 34 kg (75 pounds) be rolled down a slope over the fabric. When stones are being dropped through 1.5 meters (5 feet) or more of water, weight of 1,800 kg (2 tons) will not damage the plastic filter.

PRODUCT INFORMATION SOURCE:

Carthage Mills, Inc.
Erosion Control Division
124 West 66th Street
Cincinatti, OH 45216
Telephone 513-242-2740

Table 8-3 (cont.)

POLY-FILTER X

PRIMARY USAGE:

Used as a replacement for graded filter systems and filter blankets for drainage systems. Also used for erosion control.

DESCRIPTION:

Poly-filter X is a cloth woven from polypropylene monofilament yard. It has a thickness of 17 miles (0.017 inches) and weighs 7.2 oz/yd^2 (244 gm/m^2). Poly-filter X is not affected by salt water, bacterial decay or weathering. The equivalent opening size (EOS) is 70 mesh with 5.2% open area.

Manufactured in 1.8m (6 feet) widths and multiples thereof up to 25.6m (84 feet) and lengths from 15.2m to 274m (50 feet to 1,200 feet) depending upon width. Supplied with grommets for securing purposes.

INSTALLATION INSTRUCTIONS:

Each specific site may require some modification or variation of the general criteria listed below. Manufacturer technical representatives or specialists experienced in the use of this produce should be consulted for guidance. In general, the material is rolled out onto the prepared surface and secured with specially designed pins, staples or rods. Where more than one sheet is required, they should be lap jointed to ensure continuous coverage of the area to be protected. When in place, the succeeding layer of materials, i.e., rock, gravel, can be placed on the filter sheet. Heavy and/or sharp materials should be placed with care in order that the integrity of the sheet can be maintained.

LIMITATIONS:

Stones weighing up to 113kg (250 pounds) may be dropped from 0.9m (3 feet) without damage to the cloth. Subsequent layers may be dropped from greater heights but never more than about 3m (10 feet). In no case should stones weighing over 34kg (75 pounds) be rolled down a slope over the fabric. When stones are being dropped through 1.5m (5 feet) or more of water, weights of 1,800kg (2 tons) will not damage the plastic filter.

PRODUCT INFORMATION SOURCE:

Carthage Mills, Inc.
Erosion Control Division
124 W. 66th Street
Cincinnati, OH 45216
Telehphone 513-242-2740

Table 8-3 (cont.)

TYPAR

PRIMARY USAGE:

Used as a separation barrier to isolate two types of soil or aggregate particles. As a restraint layer, redistributes stress by transference along the membrane.

DESCRIPTION:

Typar is a nonwoven fabric manufactured from continuous filaments of a spun bonded polypropylene. Typar is manufactured in two lengths: 135 grams per square meter (4 ounces per square yard), 15 mils (0.015 inches) thick and 200 grams per square meter (6 ounces per square yard), 25 mils (0.025 inches) in thickness. The fabric can be purchased in widths of 3.8 meters (12.5 feet) and 4.7 meters (15.5 feet) in lengths of 90 meters (100 yards), 275 meters (300 yards) and 900 meters (1,000 yards).

INSTALLATION INSTRUCTIONS:

All large stones and branches should be removed and the surface should be graded to smooth out ruts, grooves and uneven patches where there is more than a 6 inch difference in grade. This facilitates unrolling the Typar and ensures an even thickness of topping. Extra widths can be obtained by overlapping the fabric a minimum of one foot or using a sewn joint. Aggregate cover should be dumped and pushed or spread with a dozer. A minimum of one foot of cover should be kept between truck or dozer tracks and the bare fabric. Typar can be patched by overlapping a piece at least 1-1/2 feet larger than the hole.

LIMITATIONS:

The polypropylene fabric degrades under prolonged exposure to ultraviolet light.

PRODUCT INFORMATION SOURCE:

E. I. duPont Textile Fibers Department
Center Road Building
Wilmington, DE 19898
Contact: Dick Hutchins, 302-999-2615

E. I. duPont
Suite 601
400 Building
400 - 108th Street, N.E.
Bellevue, WA 98004
Contact: Walter E. Partridge, 206-455-4500

HOLD/GRO

PRIMARY USAGE:

Erosion control.

DESCRIPTION:

Hold/Gro is a combination of knitted synthetic netting interwoven with paper strips, manufactured with different combinations of paper and yarn to fit the desired lifespan. Weighs 2.8 oz/yd^2 (98 $^{gm}/m^2$) and comes in 5- and 10-foot widths and 360-foot lengths.

INSTALLATION INSTRUCTIONS:

All irregularities such as gullies, large roots, and other obstructions should be removed and fertilizing and seeding completed. On slopes flatter than 2:1 the fabric should be applied horizontally. However, if the length of the slope exceeds the width, the fabric should be applied vertically. If the slope is steeper than 2:1, apply the fabric vertically. On slopes with excessive runoff from adjacent areas, the fabric should be applied vertically regardless of degree of slope. The fabric should be buried in a trench or under a berm at the toe and crown of the slope. The fabric should be draped loosely and stapled at intermediate overlaps. Optimum performance requires that the fabric remain as closely in contact with the soil surface as possible.

Ground cover plantings may be made through holes cut in Hold/Gro. For best results, the fabric should be on the ground for two days or longer to permit the Hold/Gro to assume the shape of the ground below.

LIMITATIONS:

None stated in manufacturer's literature.

PRODUCT INFORMATION SOURCES:

Gulf States Paper Corporation
P. O. Box 3199
Tuscaloosa, AL 35401
Phone 205/553-6200

MONOFILTER

PRIMARY USAGE:

Used as a replacement for graded filters in drainage systems. Also used for erosion control.

DESCRIPTION:

Monofilter is a cloth woven from polypropylene monofilament yarn. It has a thickness of 20 mils (0.02 inches) and weighs 7 oz/yd^2 (245 gm/m^2). Monofilter is resistant to acids and alkalies, is rot proof, mildew proof, and unaffected by moisture. Monofilter has been specially treated with UV inhibitors to give maximum resistance to ultra-violet degradation. Equivalent opening size (EOS) is 70 mesh.

INSTALLATION INSTRUCTIONS:

Each specific site may require some modification or variation of the general criteria listed below. Manufacturer, technical representatives or specialists experienced in the use of this product should be consulted for guidance. In general, the material is rolled out onto the prepared surface and secured with specially designed pins, staples, or rods. Where more than one sheet is required, they should be lap jointed to insure continuous coverage of the area to be protected. When in place, the succeeding layer of materials, i.e. gravel, rock, can be placed on the filter sheet. Heavy and/or sharp material should be placed with care in order that the integrity of the sheet can be maintained.

LIMITATIONS:

Stones weighing up to 113 kg (250 pounds) may be dropped from 0.9 m (3 feet) without damage to the cloth. Subsequent layers may be dropped from greater heights but never more than about 3 m (10 feet). In no case should stones weighing over 34 kg (75 pounds) be rolled down a slope over the fabric. When stones are being dropped 1.5 m (5 feet) or more of water, weights of 1800 kg (2 tons) will not cause damage.

PRODUCT INFORMATION SOURCE:

Menardi-Southern
1201 West Francisco St.
Torrance, CA 90502
Phone 213/321-8910

Table 8-3 (cont.)

PERMEALINER (Needle-Punched)

PRIMARY USAGE:

Provides subgrade restraint and separation. Can be used in fabric wall construction, silt fences for erosion control and filtration in non-critical areas.

DESCRIPTION:

Needle-punched Permealiner is manufactured in the following dimensions:

Fabric No.	Weight (oz/yd^2)	EOS
2475 & 2577	4	120
3002	8	100

INSTALLATION INSTRUCTIONS:

None specified.

LIMITATIONS:

None specified.

PRODUCT INFORMATION SOURCE:

Staff Industries
78 Dryden Road, P. O. Box 797
Upper Montclair, NJ 07043
Phone 201/744-5367

* 2475 is black; 2577 is tan

Table 8-3 (cont.)

PERMEALINER (Woven)

PRIMARY USAGE:

Used as a replacement for graded filter systems and filter blankets for drainage systems. Also used for erosion control.

DESCRIPTION:

Permealiner is a cloth woven from polypropylene yarn. Permealiner is manufactured in the following dimensions:

Permealiner No.	Weight oz/yd^2	EOS	% Open Area
M-1192	6.8	30-50	9-15
M-1195	7.2	70-100	4-10
M-1196	7.2	50-100	4-15
M-1197	7.2	30-100	4-20

INSTALLATION INSTRUCTIONS:

None specified.

LIMITATIONS:

None specified.

PRODUCT INFORMATION SOURCE:

Staff Industries
78 Dryden Road, P. O. Box 797
Upper Montclair, NJ 07043
Phone 201/744-5367

NOTES:

Table 8-3 (cont.)

SUPAC

PRIMARY USAGE:

Used as a separation barrier to isolate two sets of soil or aggregate particles. As a restraint layer, redistributes stress by transference along the membrane.

DESCRIPTION:

Supac is a nonwoven polypropylene fabric. Supac is manufactured in 15-foot (4.5 m) wide by 300-foot (90 m) long rolls weighing 4.1 oz/yd^2.

INSTALLATION INSTRUCTIONS:

Sharp objects should be removed from the area to be stabilized to avoid fabric punctures. Keep at least one foot of aggregate between the fabric and truck tires. If the fabric is damaged during construction, a patch can be made using Supac and a standard overlap of 1 to 2 feet.

LIMITATIONS:

Will degrade with exposure to sunlight. Where such exposure is necessary, the fabric should be coated with an asphalt emulsion.

PRODUCT INFORMATION SOURCES:

Phillips Fibers Corporation
Box 66
Greeville, SC 29602
Atten: Petromat Marketing
Phone 803/242/6600

NOTES:

CHAPTER 9: OTHER USES

I. Several other uses have been made of fabrics. By far the largest use is in asphalt pavements for prevention of reflection cracking and waterproofing. Uses discussed in this chapter should be considered to be in the trial-use category. Following is a partial listing of some of these uses:

A. Floating log rafts in Alaska have been protected from marine borers using fabrics. It appears that this concept could be used in other types of marine construction where marine borers are a problem.

B. Polyethylene film netting is used to protect newly planted trees from rodents and other small animals. It is also used to provide shade in plant nurseries.

C. Pond and ditch linings of non-woven fabrics saturated with asphalt make effective waterproof linings. They may sometimes be substituted for the conventional rubber and plastic liners. Construction for both systems would be similar with exception of the in-place asphalt application.

D. Trail construction - Fabric uses for road construction and maintenance are also applicable for trails. Figure 9-1 illustrates current methods of trail construction across soft ground and a proposed method using fabrics.

E. Bridge deck salt protection - Fabrics are incorporated with an asphalt overlay and effectively waterproof the deck, thus preventing salt intrusion. The construction method is the same as in pavements and will be discussed under pavements.

F. Stop-gap maintenance - Sometimes a pavement can be saved if timely maintenance is performed when distress first appears. A combination of a permeable pavement and a water sensitive base and/or subgrade can cause rapid failure. Permeable pavements can be the result of aggregate gradation used in the mix, low field density, cracking, etc. Cracking can be caused by thermal conditions, structural weakness or fatigue. Structural weakness can generally be traced to underdesign.

   Whatever the reason for the porous pavement, complete failure can be averted if the surface pavement layer can be waterproofed by a stop-gap treatment until permanent repairs are made. An asphalt saturated non-woven fabric can be used for this purpose. The fabric can be placed rapidly and will carry traffic for a limited period. For extended traffic chips are also required.

   This was tried by the Siskiyou National Forest to save a pavement from complete failure in the winter of 1976. The required construction methods are discussed in the next section.

II. PAVEMENT MEMBRANES

Non-woven fabrics have been tried extensively for pavement enhancement. Considerable success has been claimed. Although the theory behind the benefits achieved are not well established, it appears to be

the result of: a) waterproofing, and b) the formation of a stress-relieving layer. The most common use has been to prevent reflection cracking.

They are generally used in conjunction with an asphalt overlay. The construction method consists of:

A. Cleaning and filling all cracks over 1/8 inch wide.
B. Shooting the old pavement surface with an AR 2000 or 4000 grade asphalt cement at an application rate of 0.10 to 0.15 gallons per square yard.
C. Roll out the fabric and smooth with hand pushbrooms to eliminate all wrinkles.
D. Apply another shot of asphalt at a rate of about 0.10 gallon per square yard. This shot should be adjusted to completely saturate the fabric.
E. Apply the asphalt overlay.

Figures 9-2, 9-3 and 9-4 illustrate placement of fabric and asphalt overlay.

Some researchers report that the fabric layer can be substituted for 1 to 1-1/2 inches of asphalt concrete in a pavement. If this conclusion is true, it is probably more a result of waterproofing than a strength contribution of the membrane. The membrane can effectively eliminate surface water in the pavement due to surface infiltration, thereby stabilizing the internal pavement environment

and the subgrade. The high elongation properties of the fabrics and fabric filaments normally preclude their making a large contribution to the pavement strength at the comparatively low strains normally encountered in adequately performing pavements.

Majidzadeh (26) states that the structural requirements must be satisfied before the beneficial effects of the fabric can be demonstrated. A close examination of other research data resulting primarily from test road sections appears to substantiate this conclusion.

For the present, we recommend the following design procedure:

A. Uncracked Pavement (no reflective cracking problem):
   Overlay thickness is the thickness required by the structural need of the pavement.

B. Cracked Pavement (potential reflective cracking):
   Overlay thickness is the thickness required by the structural need of the pavement plus the thickness required to prevent reflection cracking; 2-1/2 inches (dense graded hot mix) without fabric, or 1-1/2 inches with fabric.

A 4-ounce per square yard, or heavier, needle-punched non-woven fabric is recommended. The wovens and the hot-rolled heat-bonded fabrics are not recommended for waterproofing or crack reflection prevention because their smaller thickness allows them to hold less asphalt and makes them more sensitive to variations in the asphalt application rate.

Some unreported work by researchers indicates that a shot of 0.20 to 0.25 gallon per square yard of asphalt without fabric may be as effective as with fabric in reducing reflection cracking. They theorize that cracks which develop heal themselves if a supply of asphalt is available. This laboratory work has not been verified in the field. Large areas treated in this manner would probably fail by slippage similar to an application of a tack coat that is too heavy. This should not be a problem on very small areas or widely spaced cracks, i.e., thermal cracks.

Fabrics have also been used with seal coats and surface treatments. Their principal benefit is probably derived from waterproofing.

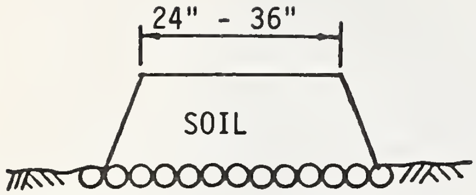
An application which may have promise is in conjunction with open graded pavements placed over water sensitive bases and/or subgrades. When placed below or between lifts of the open graded material, it should provide the needed water barrier or seal.

Several other references are available and are listed from (29) to (31).

Figure 9-1: Placing non-woven fabric on pavement using hot sprayed asphalt.

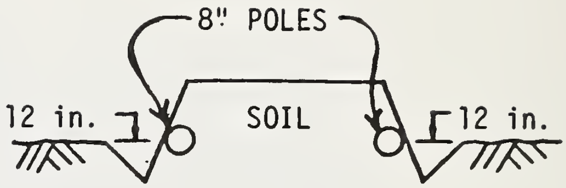
Figure 9-2: Paving over the non-woven fabric with hot mix.

Figure 9-3: Closeup view of the paving operation.



CORDUROY BASE TURNPIKE

(WITHOUT DITCHES)



STANDARD TURNPIKE

(WITH DITCHES)

a. CURRENT METHOD TO CROSS SOFT AREAS.

(WITHOUT DITCHES)

(WITH DITCHES)

b. PROPOSED METHOD TO CROSS SOFT AREAS.

FIGURE 9-4: Fabrics for Trail Construction Across Soft Ground